Characterisation of Polymer-based Wood-substitute for Sustainable Building and Construction

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This is to certify that, except where specific reference is made, the work described in this thesis is the result of work carried out by the candidate. Neither this thesis, nor part of it, has been presented or is currently submitted in candidature for any other degree at any other university.

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ABSTRACT

Materials have always been used for the commodities and convenience of mankind. However, the recognition of the impacts of the global demand for materials and resources has been leading to a growing concern with regards to production and consumption patterns, resources scarcity and waste management. With the increase of plastic consumption by a factor of twenty in the past sixty years, packaging and packaging waste are one of the various factors accounting for these concerns. This research has reviewed the role of sustainability in relation to building and built environments, the need for sustainable construction, as well as waste management, its policies and directives, in order to evaluate current trends with regards to the use of waste as resource. This research has shown that the use of waste recycled polystyrene can be a suitable and sustainable wood-substitute in building and construction industries. Extensive laboratory work had been carried out to characterise the performance of the material under investigation. Recycled waste expanded polystyrene, converted into polymer decking material (B001, B002 and B003), typical softwood (TSW), hardwood decking (HWD) and softwood decking (SWD) have been assessed for comparative analysis. During the initial testing phase the polymer material was being analysed and compared to TSW. After the initial assessment it was evident that a thorough comparison would only be possible with specimens within the same characteristics (HWD and SWD). Results demonstrated that key parameters of density, water absorption, thermal conductivity and effects of weathering are within acceptable engineering standards. Results also shown that the polymer material has low compressive and flexural strength and experience variations under extreme temperatures (above 90˚C). The results obtained from the modulus of rupture suggest that for a construction of the same area, extra material would be needed to support the polymer decking. Overall, the results suggest that the polymer material is an attractive wood-substitute for a wide range of applications in building and construction industries. Nevertheless, there are limitations due to strength constraints. The polymer material would be more suitable than wood for outdoor applications such as decking, urban furniture, cladding, and playground structures. This research has demonstrated that the use of recycled polymer to substitute wood would reduce waste and provide a long lasting material, minimising costs and maintenance related to damages raised from weather exposition, temperature variations, root and fungi attack.

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LIST of ABBREVIATIONS and SYMBOLS

α	Coefficient of linear thermal expansion
ΔL	Change in length (mm)
ΔT	Difference between plates temperatures (K) Change in temperature (˚C)
Δx	Thickness of the sample (m^{-1})
E	Young's Modulus (N/mm^2)
ε	Strain
λ	Thermal Conductivity ($W\ m^{-1}\ K^{-1}$)
ρ	Density (kg/m^3)
σ	Stress(N/mm^2)
ω	Moisture content
3BL	Triple Bottom Line
6^{th} EAP	6^{th} Environmental Action Programme 2002
A	Area (mm^2)
A_c	Cube area (mm^2)
ASTM	American Society for Testing and Materials Standards
B	Boron
BS	British Standards
B001	Polymer Decking Block Batch 1
B002	Polymer Decking Block Batch 2
B003	Polymer Decking Block Batch 3
BMCC	Building Materials and Component Combinations
C	Carbon
˚C	Degree centigrade
Cl	Chlorine
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DEFRA	Department for Environment, Food and Rural Affairs
EA	Environment Agency
E_c	Modulus Elasticity at Compression
EC	European Commission
EEA	European Environment Agency
EMS	Environmental Management Systems
ELC	End-of-Life Cycle
EOL	End-of-Life
EPS	Expanded Polystyrene
EU	European Union
EU15	Europe 15 (European Union countries 1995-2004)
EU27	Europe 27 (European Union countries 2006 onwards)
f_c	Maximum stress at failure (N/mm^2)
f_m	Maximum bending at failure (N/mm^2)
F	Force (N)
F	Fluorine
g	Gram
GDP	Gross Domestic Product
GHG	Greenhouse Gas
h	High/Thickness
H	Hydrogen
HWD	Hardwood Decking Block

IEA	Integrated Environmental Assessment
IPP	Integrated Policy Product
IPPC	Integrated Pollution Prevention and Control
K	Kelvin
kg	kilogramme
kN	kiloNewton
kN/s	kiloNewton per second
l / L	Length
L_D	Length of oven dry specimen
L_O	Original Length
LCAs	Life Cycle Analysis
LCA	Life Cycle Assessment
m	Metre
mm	Millimetre
MSW	Municipal Solid Waste
MSWI	Municipal Solid Waste Incineration
N	Nitrogen
O	Oxygen
OECD	Organisation for Economic Co-operation and Development
P	Phosphorus
PS	Polystyrene
q	Heat flux (W/m^2)
S	Sulphur
SO_2	Sulphur Dioxide
SL	Shrinkage Limit
SMEs	Small and Medium Enterprises
SD	Sustainable Development
Si	Silicon
SWD	Softwood Decking Block
T_L	Lower plate temperature
T_U	Upper plate temperature
TSW	Typical softwood
UCS	Unconfined Compressive Strength
UK	United Kingdom
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UV	Ultra Violet
w	Width
w_D	Weight of oven dry specimen
w_w	Weight of wet specimen
W	Watts
W_w	Rate of water Absorption (%)
WFD	Waste Framework Derivative
WM	Waste Management
WMP	Waste Management Policies
WMS	Waste Management Systems
WPC	Wood-plastic Composites

LIST of EQUATIONS

CHAPTER 1

INTRODUCTION

This chapter explains the background to the research, gives an overview of the problem definition as well as the aims and objectives of the research. The chapter also contains a brief description of the structure of the thesis.

1.1. BACKGROUND TO THE RESEARCH

There has been an unprecedented growth of the world population in the last century. This has been causing an exceptional impact on the world's consumption of natural resources. Due to that there has been rapid change in external conditions on the balance of world environment and economy.

In the past seventy years the production and consumption of materials and consumer goods has increased, bringing about ecological concerns related to disposal and recycling of these materials. During the past decades, most human activities were greatly linked to fossil fuel consumption, a factor that has led to subsequent environmental impact (Gaidajis *et al.*, 2011). Consumption and technology are the primary drivers of environmental change (Krausmann *et al.*, 2009; UNCED, 1992). As the world's population increases, there is an increase in the inputs of resource and energy into socio-economic systems, and a corresponding outflow of waste and emissions, resulting in subsidence of the Earth's capacity to create new resources and absorb waste, thus, presenting a major threat on our planet.

The understanding that waste generation is intrinsically linked to population growth, and consequently, responsible for the depletion of materials, scarcity of resources, climate change, carbon emissions, water and energy usage is one of the key targets and concerns of sustainability (Doughty and Hammond, 2004; UNCED, 1992). The present trends and the knowledge that more materials will have to be extracted or harvested to meet the changing lifestyle and growth of the world population, shows that the disposal of used materials has become a serious universal problem in recent years (Wagner, 2002). Thus, mankind is faced with the need to sustainably use and manage resources to stabilise and/or reduce the environmental burden.

Sustainability brings about the social, economic and environmental needs of our societies and their capacity to undergo maintenance, regeneration and nourishment taking into account environmental and developmental aspects. Sustainability has become a key concept following the publication of the 1987 Brundtland Report and the 1992 Rio Earth Summit. According to Mora (2007) the sustainability concept has also been applied to characterise a type of development, commonly known as "sustainable development" (SD). Currently, after being given further prominence following the Johannesburg 2002 World Summit on Sustainable Development, SD is rapidly becoming a universal phenomenon with different paradigms, focussed on interdisciplinary subjects that involve series of different fields.

From an engineering perspective, the environmental impacts of building and construction industry are one of the main factors responsible for environmental change. The adverse impact of their activities causes changes on the natural environment leading to irreversible transformations on the conservation and management of resources. The exploitation of resources used in construction and building industries is by nature environmentally unfriendly. These factor forces these industries to shift towards sustainability (Yuan, 2012).

There are many principles being developed globally to apply more sustainable ways in construction and building industries, resulting in many good practices being adopted. For instance, Habert *et al.* (2012) states that the building materials sector is the major contributor to the extraction, consumption and dilapidation of natural resources, due to the fact that the industry directs the sources of power in nature for the use and convenience of mankind. This statement is supported by a *Willmott Dixon* (2010) report that states that building and construction industries are the largest exploiters of natural resources and also the world's largest users of non-renewable energy sources. In the same line, Spence and Mulligan (1995) suggested that together with the materials industry, which supports it, construction industry is one of the major global exploiters of natural resources, both physical and biological.

More than ever the construction industry is concerned with the improvement of the social, economic and environmental indicators of sustainability (Ortiz *et al.*, 2009). Sustainability represents reduction, recycling and recovery of material consumption and processing. Notwithstanding that some researchers like Doughty and Hammond (2004) have stated that when applied to construction industry, sustainability can be interpreted in different ways. Others, like Mora (2007), have suggested that the construction industry will only achieve sustainability when the use of renewable energy sources and renewable materials derived from construction waste or other industrial waste are applied in construction.

In the United Kingdom (UK), European Union (EU) and worldwide, consumption and waste are the biggest factors contributing to the environmental burden. Waste management has become an indispensable consideration in a product/material life cycle. Waste producers have been trying to find alternative solutions to landfill disposals, not only due to costs and stricter legislations but also due to the increase in social pressure and environmental commitments such as ISO 14001 (Chateau, 2007). In these times, the shortage of environmentally friendly materials has been leading to investigations and pursuits of alternative resources. Using waste as a resource for materials and technology might be the behavioural transformation and the answer to reduce global patterns of resource consumption.

1.2. PROBLEM DEFINITION

Since the industrial revolution humanity has continuously expanded and enlarged industrial production and urbanisation, using a considerable amount of resources, materials and energy (Lehmann, 2011). Over the last century the world population has quadrupled to 6.4 billion and the global economic output, measured as gross domestic product (GDP), have grown more than 20 times, a factor that has caused an expansion of the global socio-economic system, leading to fundamental changes in society's regular affairs, transforming the ecosystems (Krausmann *et al.*, 2009; Apelian, 2012).

In the past few decades population growth has been accentuated, especially in developing countries, a trend that is set to continue as some of the world's fastest growing and larger cities are in countries of low income (Wagner, 2002; UNEP, 2003). Although growth represents development, these unparalleled demographic trends translate into increased demand for infrastructure and building, representing an increase in materials consumption, fed by equally unprecedented natural resource consumption and environmental impact (Krautkraemer, 2005).

Today's global society is economically, socially and culturally dependent of mineral resources. Production and consumption trends are driven by the demands of middle to high income countries and it's reaching unparalleled levels in low income countries (Prior *et al.*, 2012; UNEP, 2011). The demand for materials and goods has been coupled with remarkable environmental changes raises concerns on the continuation of production and consumption. These trends translate into increased demand for building and infrastructure in high income countries, while in low income countries the construction only meets "informal" housing, lacking basic infrastructure (UNEP, 2003).

Induced by the demographic growth, the trade and industrial activities require land, materials and energy resources which are invariably conveyed in material residue. Although global stocks are still sufficient to meet the demand for most of the materials used to provide building, infrastructure and consumer goods, the environmental impact of such production are rapidly becoming critical (Allwood *et al.*, 2011). According to the World Wide Fund for Nature (WWF, 2010), the demand of natural resources has doubled since 1966, and the current global resource usage to support our activities is equivalent to 1.5 of our planet. Furthermore, at the beginning of the new millennium, global mineral extraction was estimated to range between 47 and 59 billion tonnes per year, if present trends do not change, the development of the built environment is estimated to destroy over 70 per cent of the Earth's land surface by 2032 (Steinberger *et al.*, 2010; Krausmann *et al.*, 2008; UNEP, 2003).

Of all materials used in the past hundred years, more than half were used in the last 25 years, and, as the peak mineral approaches, current consumption may force future generations to accept a lower standard of living (Matos and Wagner, 1998; Tilton, 1996). Understanding the dynamics of material production, use, recycling and dematerialization is essential to establish mechanisms for sustainable resource governance (Ashby, 2012; Behrens *et al.*, 2007). The only way forward passes through find a more sustainable and benign way to respond to our societal needs (van der Lugt *et al.*, 2006) by beholding the flow of materials in a holistic perspective enabling for a broader vision of potential problems and allowing the development of preventive measures.

The recognition of the impact of consumption and industry on the environment resulted in worldwide initiatives to influence and shift consumption patterns towards more sustainable behaviour, in order to reduce the amount of materials and natural resource demands among the different industries. When a material/product reaches its end-of-life cycle (ELC) the available waste can be recycled or even transformed into a new product, as so, rely on recycling comes as an economic and environmental important alternative to minimise the world's materials demand (Mohamed, 2010; O'Brien, 1999; UNEP, 2010; UN, 2002).

In engineering, materials have always been used for the commodities and convenience of mankind. Nonetheless, the concerns related to the shortage of materials, resource scarcity, waste management, and the overall effect of these factors on livelihood have resulted in a set of initiatives to evaluate current practices and to make new solutions to open channels for the development of new practices. Over a decade, numerous industrials and public initiatives have been launched in order to make knowledge, practices and mentalities evolve in relation to the acceptability of using waste instead of raw material as resource. According to, Chateaux (2007) scientific and standardisation communities have developed methodologies and tools to fit with the assessment needs expressed by industrialists and public decision-makers.

Due to materials and resources limitations, there is a continuous need to use and develop materials with enhanced life-cycle to enable the reduction of resource consumption and reuse of resources. The development of a new product that uses waste as resource, not only enables the reduction of natural resource consumption and depletion, but also helps to prevent and minimise the amount of residues and waste generated, allowing for material recover and improved disposal at the ELC of the material.

With the increased growth and demands of the world population, packaging has considerably increased around the world. According to UNEP (2009) the world's annual plastic consumption has increased by a factor of twenty in the past sixty years and this trend is corroborated by Eurostat (2011) packaging waste statistics which states that plastic waste accounts for 18 per cent of the packaging waste share. Understanding that waste streams from different industries can be resourceful for one another and minimise the demand for new raw materials are the main aspects that encourage the development of this research work.

This study uses polymer packaging waste as resource material to substitute other materials, more specifically wood, on building and construction industries applications. Furthermore, the purpose of this study is to achieve effectiveness in packaging waste recycling, in order to reduce the overall generation of material residues and also to minimise to some extent, their environmental impacts.

The aims of this research are:

- To carry out applied research for the development of a new construction material for a more sustainable construction industry;
- To carry out laboratory experiments to understand the engineering properties of the material;
- To establish and specify the optimal performance; and
- To establish an environment profile for the new construction material.

This work also aims to highlight the holistic vision of possible uses that waste can have on the conception of new alternative materials for the building and construction industry.

1.3. RESEARCH OBJECTIVES

In order to achieve the aim of this research, as explained at the end of section 1.2 (Problem Identification), the research objectives established for this project endeavours to complete the following:

- A thorough literature review to establish the level of current thinking and knowledge on sustainability; sustainable development (SD), construction and materials; waste management (WM); packaging waste recycling; end-of-life cycle (ELC); and polymers. These topics were chosen to provide intellectual context to the research.

- In order to achieve the purpose of this research, experiments will be carried out to determine the characeyeristics of the material.

- Detailed laboratory experimentation and testing of the mechanical properties of the object of study (polymer decking specimens), and its object of comparison (wooden decking specimens) to determine the new material capacity for further development and use as new building material.

- The key engineering properties of the end product to be monitored are: density, rate of water absorption, flexural and compressive strength, thermal conductivity, dimensional stability (shrinkage/swelling, creep, thermal expansion), freeze–thaw, effects of weathering and ultra violet (UV) light, and bonding.

- The establishment of the environmental profile of the new material and the social acceptance, so as to get an indication of the carbon and energy inventory in terms of energy inputs and emissions outputs for the product manufacturing process the possible integration of the material in the trade market.

By using a recyclable polymer converted in a new material this product accounts at some extent to changes in production patterns, not only in terms of life cycle assessment (LCA) but also in terms of resource depletion minimisation and reduction of carbon footprint.

1.4. STRUCTURE OF THE THESIS

The research work was laboratory based. The body of this thesis consists of seven chapters. Following this introductory chapter the organisation of the chapters is summarised below:

Chapter 1 provides an introduction to the research, explaining the nature of the current problem. In order to address the problem, aims and objectives of the research methodology are described in this chapter;

Chapter 2 reviews existing literature and explores the problems related to the research. This chapter explores the current state of building and construction industry correlating to patterns of resource consumption and waste generation. Additionally, this chapter provides basic information about polymers;

Chapter 3 describes the characteristics and provides insight detail of the materials used to carry out the research work (materials source and reasons for using it);

Chapter 4 describes the methodology used to carry out the experiments. Engineering tests on properties performance and durability are specified in this chapter;

Chapter 5 outlines the results obtained from the current research. Detailed data from the various tests are presented in this chapter;

Chapter 6 analyses the results obtained from the different tests and observations and discusses correlations the arising from the research. Additionally, environmental impact assessment indication and practical implications are provided; the chapter also integrates and summarises the main conclusions, providing also the recommendations for further research work.

CHAPTER 2

LITERATURE REVIEW

This chapter gives an overview of the concepts of sustainability and sustainable development, its applications in construction industry and correlation with resource consumption; makes a review of waste management, waste directives, packaging recycling and end-of-life cycle; and provide basic information about polymers. This literature review aims to provide knowledge source information behind the development of the concept for the current study.

2.1. SUSTAINABILITY

The rapid growth of the world's population and the dynamic pattern of the human-environment relationship have been causing changes in the global social metabolism. Over the past few decades, population demographics instigated a growing concern about the scale of human impact on the planet. As a result, the concept of sustainability have been acknowledge as the key intergovernmental model to preserve ecosystems, stabilise the economy and maintain social security and justice on the planet. (Green *et al.*, 2012; UNCED, 1992)

Achieving sustainability will allow the planet to continue to provide for humanity. Generally speaking sustainability is defined as the capacity to bear, preserve, upkeep, endure and support life. In the last two decades of the twentieth century, the concept of sustainability started to be defined as the balanced relationship of the society, economy and environment, triple bottom line (3BL) systems towards global stewardship (Green *et al.*, 2012), see Figure 2.1.1.

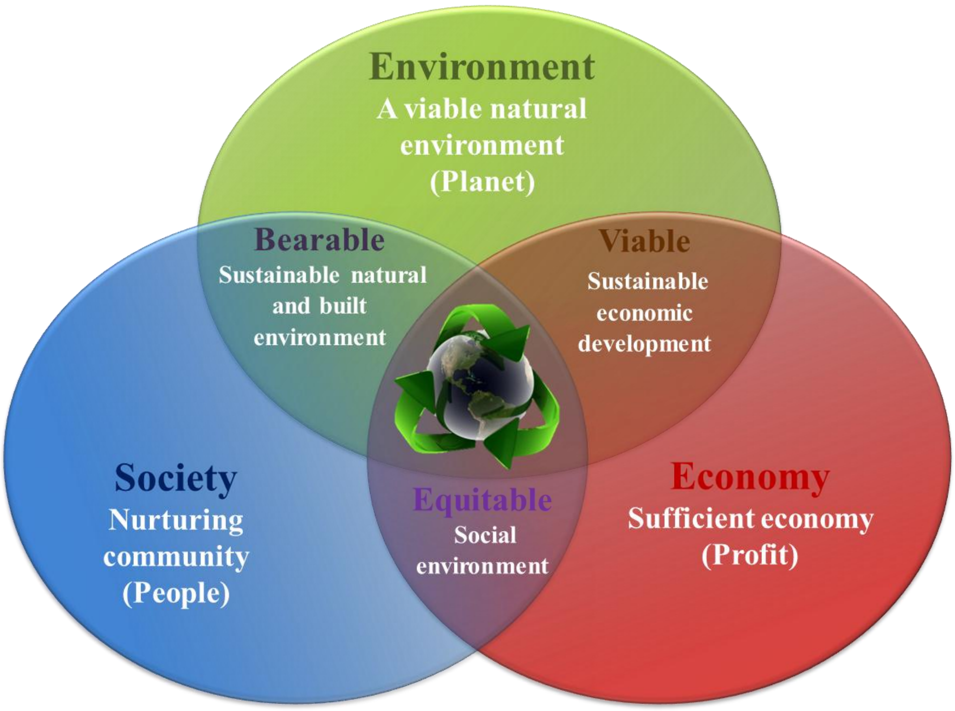

Figure 2.1.1: Triple bottom line of sustainability. (Source: author)

Sustainability is driven by the 3BL systems, environment, economy and society, which are accordingly its basis, tool and target. The basis (environment) is under strain from human activities. Thus there is a need to reduce the environmental impacts of human activities, tackle climate change and limit global warming. Measures to reduce the emissions of gases from fossil fuel and carbon need to be implemented shortly on behalf of the planet. The tool (economy) is a very important element of sustainable development (SD). The effectiveness of reducing environmental impacts depends on it. This means that all the costs, for any activity, must be taken into account when economic and business decisions are made, in order to achieve prosperity. The target (society), social dimension, needs the supports of the civil society to make amends and arrange ways to create potential, meeting people needs (EEA, 2006). Nevertheless, the recognition and underlying assumption that these systems are inextricably linked do not preclude them of having distinct gain. Only the provision for a global achievement and equitable involvement will provide for a global society growth.

Sustainability embodies characteristics of different parameters from the world's social, natural and built environment with economic development. One of the key objectives and concerns to achieve sustainability is related to the capability of the countries and communities to display greater responsibility for the ecosystems on which all life depends. In the beginning of the 21st century urban centres' accounted for 3.17 billion out of 6.45 billion of the world's population, a trend set to continue, see Figure 2.1.2. Predictions estimate that 5 billion out of 8.1 billion will live in urban centres by 2030 (UN-HABITAT, 2007). Due to these demographic trends and the intensity of the economy and social activities, urban centres are the major exploiters of resources and have special importance within the broader context of sustainability.

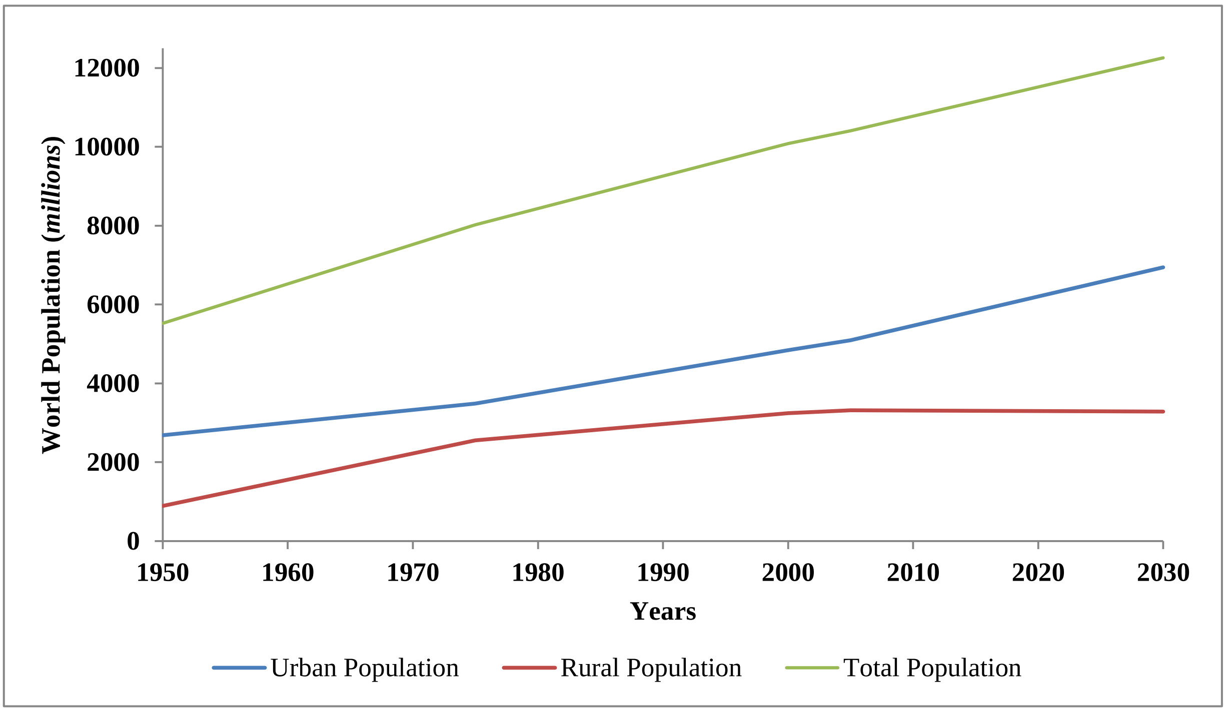

Figure 2.1.2: Urbanisation prospects. (Source: author, with data from UNDESA, 2006)

Society's urbanisation and economic development activities require the use of energy, materials and land, which generates residuals, like waste and pollutant emissions, that enter in the environment (UNEP, 2010). Therefore, understanding the importance of specific resources limitations, their environmental problems, and the ways that production and consumption affect environment and resources is of paramount importance to change patterns in economic activities.

Through industrialisation and globalisation the standard of living in developed countries has fluctuated between subsistence and affluence, while the great majority in developing countries are subjected to destitution as the environment has been reaching a limit and beginning to give vital signals (Mebratu, 1998). The need for sustainably use and reduce materials consumption as well as recycling waste is well established across industries and fields, and although there is no agreement on the precise meaning of sustainability, there is a common understanding that in most cases sustainability refers to the maintenance of human standards within economic development, and the feasibility of natural resources and ecosystems over time, and under this agreement new concepts such as SD, sustainable construction, sustainable practices or even sustainable materials evolve (Ismail, 2011).

2.1.1. Sustainable Development

In the UK, EU and worldwide, governments are trying to improve the standards of living by protecting human health, conserving the environment and by making efficient use of resources, allowing advancing and long-term economic competitiveness. For long time, environmentalists and industrialists have seen a false trade-off between environmental protection and economic growth (UN, 2002), but the challenges demanded a more robust way of thinking, one that interlinks and supports mutual goals.

With the increase of global consumption, humanity is faced with greater responsibility to reduce wasteful and inefficient consumption patterns and encourage SD (UN, 2002). The first and most well know definition of SD was established in a 1987 report by the World Commission on Environment and Developed (WCED), entitled *Our Common Future*, also known as Brundtland Report. SD was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

(WCED, 1987). This ability to meet basic human needs without compromising the social, economic and environmental requirements, protecting human health and making efficient use of resources allowing for a long-term advance of the economic competitiveness was given further prominence after the 1992 Rio Earth Summit, United Nations Conference on Environment and Development, where world leaders adopted measures to be taken for 21st century, so called Agenda 21 (UNCED, 1992). The Agenda 21 is an international blueprint that outlines global actions to achieve sustainability, actions that are actually a global recognition of the impacts of human behaviours on the environment and on the sustainability of systems of production (UNCED, 1992; UN, 2002).

Agenda 21 is divided into four sections, the first, *social and economic dimensions*, examine the underlying human factors and problems of development, with the key issues of trade and integrated decision-making. The second, *conservation and management of resources for development*, makes in-depth examination and of global resources, ecosystems and other issues that must be underpinned in detail, such as the protection of the atmosphere, the plan and management of land resources, combat deforestation, the conservation of natural diversity, the sound management of waste, and the protection of the oceans and freshwaters. The third, *strengthening the roles of major groups*, looks at the social partnerships necessary to achieve SD, and recognises that government and international agencies alone cannot achieve SD due to the fact that community must be the key in the development of policies to bring about the necessary changes. The last, *means of implementation*, examines the question the processes that need to be underlined to make all of the above tangible. This section looks also to what needs to be mobilised to support a sustainable future, and although finance and technology are key elements of education, institutional and legal structures, data and information and the creation of national capacity in relevant disciplines are cornerstones for the achievement of SD. (UNCED, 1992)

Since the 1992 Rio Summit, this ability of meeting basic human needs without compromising the social, economic and environmental requirements, protecting human health and making efficient use of resources allowing for a long-term advance of the economic competitiveness has become a global phenomenon. Whereby technological development, instruments, natural resources, and institutional arrangements are aligned as so to reduce wasteful and inefficient consumption patterns. On this regard, in the Johannesburg 2002 World Summit on Sustainable Development (WSSD), Kofi Annan stated that if we are to achieve SD, we will need to display greater responsibility for the ecosystems on which all life depends, for each other as a single human community, and for the generations that will follow our own, living tomorrow with the consequences of the decisions we take today (UN, 2002).

In the UK, the government is committed in address the concept of sustainability in all publicly funded procurement, while developing strategies and policies to shape action on SD (Carter and Fortune, 2007). In a report from the Department of the Environment, Transport and Regions (DETR, 2000), on strategy for more sustainable construction, SD is characterised as the idea of ensuring a better quality of life for everyone, now and for generations to come. The same report goes further and states that SD will give us a more inclusive society in which benefits of increased economic prosperity are shared, with less pollution and more efficient use of resources. Having in consideration the development of our societies, building and construction industries are the main consumers of resources and also one of the main producers of waste. Owing that these industries have deep connections with sustainability, they have been central on the development of SD policies (Carter and Fortune, 2007; Houvila and Koskela, 1998).

2.1.2. Sustainable Construction, Building and Materials

Construction industry is a global emerging sector with a high active industry in both developed and developing countries (Ortiz *et al.*, 2009). According to Bakens (2003), no sector has more potential to contribute to the achievement of SD than the building and constructions industries. In the UK, the economic contribution of the construction industry is significant. Yearly its output is worth over £110billion pounds and account for 8 per cent of the gross domestic product (GDP) (UKGov, 2009; UKGov, 2008). Its outputs have a major impact on our ability to maintain a sustainable economy and a major impact on the environment. Ortiz *et al.* (2009) states that construction industry is the largest employer in the EU with more than 11.8 million operatives, accounting for 7 out of the 28 per cent of industrial employment in the EU15. Relating to a 2006 European Commission (EC) overview Ortiz *et al.* (2009) suggested that about 910 billion euros was invested in construction in 2003, representing 10 per cent of the GDP of the EU15.

The economy is dependent on the performance of the built environment and infrastructures, as a modern, efficient infrastructure is a key driver of productivity. The construction industry makes an important contribution to the competitiveness and prosperity of the economy by delivering innovative infrastructures in a cost effective manner (UKGov, 2008). Worldwide, building and construction industries are a conspicuous user of resources due to the fact that their activity is the basis of almost every development. Yearly, world constructions activities, alone, consume 3 billion tonnes of raw material (Xing *et al.*, 2009). In 2008, the UK's construction activity consumed approximately 380 million tonnes of resources and produced around 33 per cent of all waste generated in England (Hobbs, 2008). So, as the world becomes increasingly conscious of the environmental implications of the construction activities there is a growing requirement for the adoption of the sustainability principle on their activities and policies.

Construction industry has been proved to be a potentially damaging exercise to the surrounding environment (Matar *et al.*, 2008). Moreover, construction has been accused of causing environmental problems ranging from excessive consumption of global resources, not only in terms of construction and building operation but also due to the pollution of the surrounding environment (Ding, 2008). Therefore, the growing interest in assessing the environmental performance of construction works and products, to address environmental considerations and set up minimum performance requirements to ensure reduction of impacts on the environment (Ortiz *et al.*, 2009; EURIMA, 2012).

A sustainable construction project should incorporate sustainability in the planning, construction, demolition and resources management stages. Although, Matar *et al.* (2008) suggests that the discipline of sustainable construction has been evolving since the late 1980's, the generally used term to describe the application of SD to the construction industry, "sustainable construction", was first introduced in the early 1990's. According to Kibert (2003), the terminology has its origins at the Powell Centre, Florida, in 1992. Kibert (2003) explains that, initially the full extent of resources consumption and waste generation was not comprehended, neither the concepts of ecology, deconstruction and reuse were established, but there was a realisation regarding problems of waste inefficiency. Consequently, after the first International Conference on Sustainable Construction held in Tampa in 1994, a definition was proposed by Task Group 16 (Sustainable Construction) of Conseil International du Batiment (CIB), an international construction research networking organization with headquarters in Rotterdam. The concept of sustainable construction was introduced and defined as *"the creation and operation of a healthy built environment based on resource efficiency and ecological principles"* (Kibert, 2003).

Kibert (2003) suggests that the international effort to change construction industry onto a path parallel to the overarching SD, referred to as sustainable construction, addresses the entire life cycle of building from planning, design, construction, operation to modifications, renovation, retrofit, and ultimate disposal (Kibert, 2003). The principles proposed him for a sustainable construction include the minimisation of resource consumption, the maximisation of resource reuse, the use renewable and recyclable resources, the protection of the natural environment, the creation of a healthy and non-toxic environment, and the pursue of quality in creation of the built environment (aesthetics, durability, maintainability, to name a few quality aspects).

Varied are the views on what constitutes SD, and more specifically related to the built environment sustainability (Kua and Lee, 2002). Kohler (1999) suggested that the purpose of sustainability is not to improve the quality of the building stock, but to improve without growth by reducing the materials throughput and improve the functional quality and its durability. Kohler (1999) suggests that sustainability in built environment can be divided into three groups, which one can considered as guide in the defining the possible dimensions, ecological sustainability, economic sustainability and socio-cultural sustainability, see Figure 2.1.3.

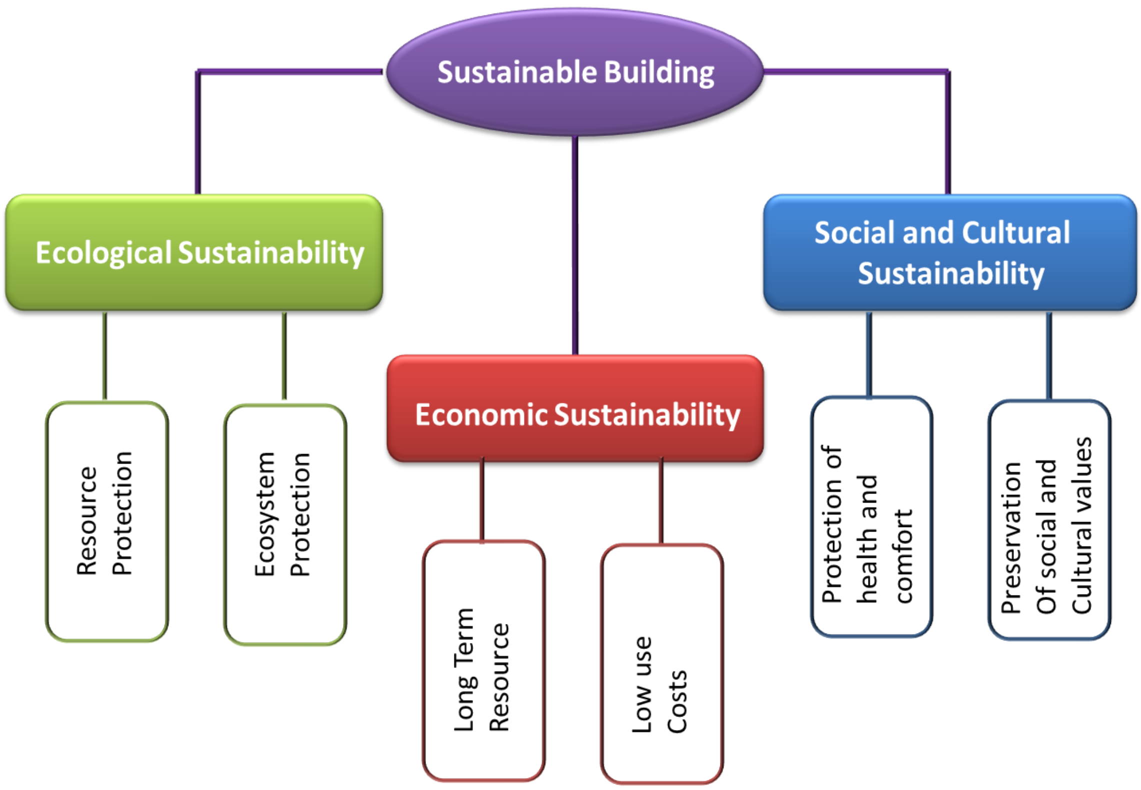

Figure 2.1.3: The three dimensions of sustainable Building adopted by Kohler (1999). (Source: author, with data from Kua and Lee, 2002)

Ecological sustainability is defined in terms of resource and ecosystem protection and can be quantitatively analysed with respect to the energy and mass flows in time and space within a life cycle assessment (LCA). The economic sustainability can be divided into investment and use costs. Given investment, it is preferable to find solutions that have the highest durability and reusability, instead of minimizing investment cost through low-cost of building process and products. The social and cultural aspects of sustainability include comfort and health protection, and preservation of values, considered one of the main motivations behind any conservation projects. (Kua and Lee, 2002)

It has become clear that construction can no longer exist dissociated from the development of other associated segments of sustainability. The idea of SD involves improving the quality of life, allowing people to live with the means to their needs without compromise others to achieve the same goals (Joseph and Tretsiakova-McNally, 2010). Bourdeau (1998) concluded the idea of sustainable construction has different approaches and different priorities in different countries.

Bourdeau (1998) states that some countries may identify social, cultural and economic parameters as part of their sustainable construction framework, the same assessment in other countries might raise major issue. The main aspect is related to the national definitions on ecological impacts to the environment (bio-diversity, tolerance of nature and resources), and the reduction of the use of energy resources and depletion of mineral resources. Under sustainable construction definition, problems related to poverty, underdevelopment or social equity are sometimes ignored, and in addition to economic prerequisites or social questions, numerous other variables should be taken into account, as for instance the country global context, see Figure 2.1.4 (Bourdeau *et al.*, 1998). A truly sustainable construction project should address the global context (social, economic and environmental parameters) on the planning, construction and demolition stages aiming to provide for an affordable, accessible and environmentally conscious project.

On its report Bourdeau *et al.* (1998) identified physical problems regarding resources, biological problems regarding mankind, and sociological problems regarding socio-cultural facets that go behind the notion of sustainable construction, and concluded that the key elements that define sustainable construction are:

- the reduction of the use of energy sources and depletion of mineral resources;
- the conservation of bio-diversity and natural areas; and

- maintenance of the quality of the built environment and management of healthy indoor environments.

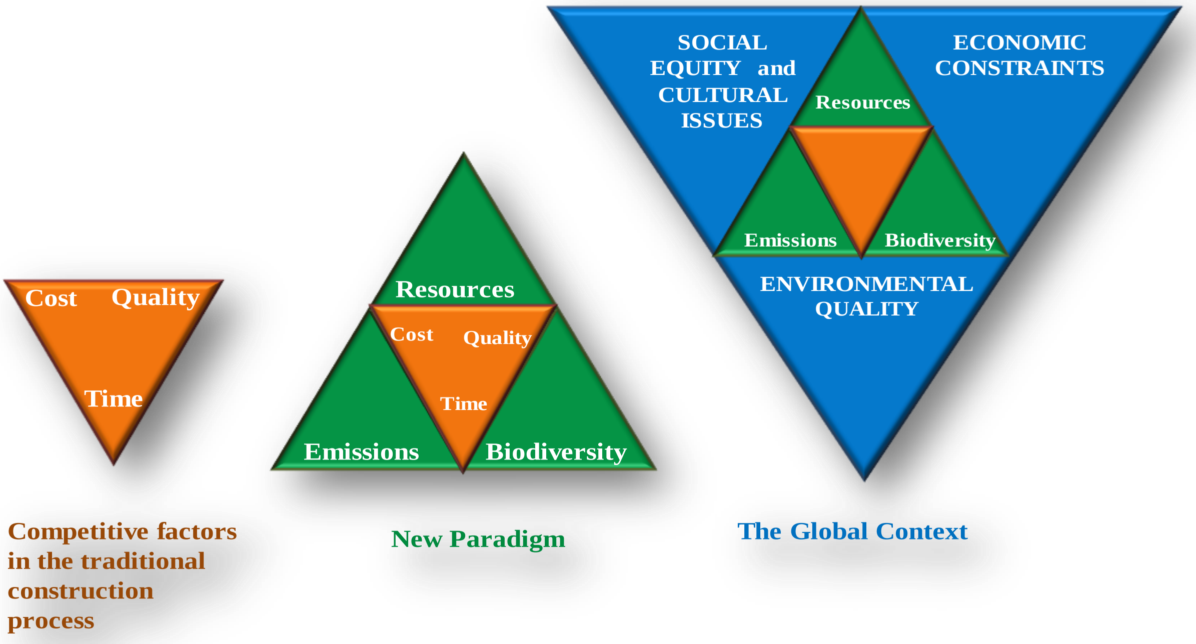

Figure 2.1.4: New approach to sustainable construction in a global context (Source: author, with data from Bourdeau *et al.*, 1998).

With the importance of sustainable construction being acknowledged, significant research efforts have been made to produce tools that help to assess and consequently mitigate the environmental impacts of building and construction activities (Matar *et al.*, 2008). The main challenges were and still are related to the efficiency in end use, greater reuse of materials, durability and maintenance, and operational energy. Although, environmental burdens caused by construction can be minimized, and technology can be used to remedy the environment, the quest towards SD in our societies puts the spotlight in the built environment and construction industry due to the industry consumption of resources (Houvila and Koskela, 1998).

2.1.2.1. Sustainable Building: the role of built environment

The massive industrialisation that enables the advance of civilisation has sifted the earth's biosphere to a new equilibrium. Since the Industrial Revolution, the burning of fossil fuels to support the energy needs of this growing population, mankind has liberated a quantity of carbon (as carbon dioxide (CO_2)) that it took our planet two hundred and fifty million years to sequester (Green *et al.*, 2012).

In the last decades, climate change, air pollution, depletion of natural resources and biodiversity, depletion and pollution of water resources, waste generation, and deterioration of the urban environment became global issue that require urgent actions to be taken (Joseph and Tretsiakova-McNally, 2010). Quoting the journal Nature, United Nations Department of Economic and Social Affairs (UNDESA, 2010) states that recent research has defined as 8 the number of Earth's biophysical subsystems that should not be exceeded to avoid major environmental disruptions, but apparently several thresholds have been already exceeded, including climate change, biodiversity and the nitrogen cycle.

According to UNDESA (2010), CO_2 emissions have been rising steadily since 1751 and approximately 329 billion tons of carbon have been released to the atmosphere from the consumption of fossil fuels and cement production. Half of these emissions have occurred since the mid-1970s. Thus, the need to cut the emissions by about 50% below current levels is imperative. Great part of CO_2 emissions occurs through the whole life cycle of a building, and this includes the production of building materials, the construction of a building itself, the exploitation, renovation and even possibly the rehabilitation and demolition of a building (Joseph and Tretsiakova-McNally, 2010).

For instance, in the UK buildings are responsible for almost half of the country's carbon emissions, half of the water consumption, about one third of landfill waste and one quarter of all raw materials used economically (UKGov, 2008). Hence, through its impacts on the built environment, construction plays a central role in the matters of building industry, and on the capacity of the industry to achieve a sustainable global environment, particularly with the regard to the use of materials and the consumption of energy (Ismail, 2011).

Moreover, the growing interest in understanding the complex interactions and feedbacks between urbanisation, material consumption and the depletion of our resources is also related to building and construction industry. The relation between the increasing urbanisation and the increase of waste generation has been established for some time, although the impact of urban morphology and density on resource consumption is still not fully understood (Lehmann, 2011).

Construction industry socio-environmental concerns are increasingly being considered alongside functional and economic aspects of built environment by architects, surveyors, engineers, project managers and others responsible for making key decisions throughout the different stages in delivering an urban development project (Xing *et al.*, 2009). Given the scale of resource flows and corresponding impacts, SD is ultimately about transforming the built environment in ways to make possible our long term survival (Kohler and Moffatt, 2003).

The design, construction and operation of environmentally friendly buildings can be more challenging than it seems, especially concerning to materials selection (Ismail, 2011). The built environment is at the origin of most of material and energy flows for which man is responsible for (Kohler and Moffatt, 2003), and with the exponential globalisation of the world, building and construction industries have to deal with several environmental issues. Biodiversity, global warming and resource efficiency, among others, are matters within the context of striving for socio-economic growth that building and construction industries have to deal with.

Some authors estimate that almost 50 per cent of total energy costs in the developed countries are consequence of intensive construction and building practices (Joseph and Tretsiakova-McNally, 2010). For instance, on their *review on buildings energy consumption information*, Perez-Lombard *et al.* (2008) suggested that in developed countries buildings energy consumption, other than dwellings, account for 20 to 40 per cent of the total final energy. The same review suggests that the UK building energy consumption has increased at a rate of 0.5 per cent per annum, which is below the 1.5 per cent in Europe. Nonetheless, Perez-Lombard *et al.* (2008) states also that in 2004 the building consumption in the EU was 37 per cent of final energy, bigger than industry (28 per cent) and transport (32 per cent) but lesser than the UK's consumption, where the proportion of energy used in buildings accounted for 39 per cent, a figure slightly above Europe.

Environmental problems caused by the building and construction industry can be minimised and construction technology can be used to remedy the environment (Houvila and Koskela, 1998). Currently, the environmental impacts of construction, green buildings, recycling and eco-labelling of materials have captured the attention of building professionals worldwide (Ding, 2008). Building performance became a major concern for professionals in the building industry, and, as consequence, environmental building performance assessment has emerged as one of the main matters in sustainable construction. For instance, 25 per cent of the new office buildings have an environmental assessment in the UK, example of building performance implementation.

With the increase environmental protection laws and the ecological awareness of public in general, as well as the costs of resource consumption, almost every country identifies the need to use energy efficiency of buildings and the built environment. Great attention is being paid to the use of renewable energy and resources, giving a range of opportunities to market innovative energy saving materials and systems throughout the building and construction industries (Bourdeau *et al.*, 1998). Building regulations, governments planning policies, industrialists' actions and public awareness have been critical on the delivering and implementation of measures to acknowledge sustainability as the main stream in built environment. The 2003 Energy Performance of Buildings Directive, implement on declaration of carbon and energy performance is a great example of this.

Worldwide great efforts have been placed onto achieving SD. Materials and environmental engineers are interested on the effect of building materials on sustainability (Mora, 2007). One of the most important components of a sustainable building is the material efficiency. To achieve the goals of SD in building construction, a combination of factors must be considered (Joseph and Tretsiakova-McNally, 2010). A correct selection of building material has to be made taking into account the complete life cycle of the material and the minimal environmental impacts of the material/product. In this context, tools to support decision makers on the finding more sustainable solution for their convenience were designed. Life cycle analysis (LCAs), LCA, cradle-to-cradle and product integrated waste management system (WMS), are some of the tools that can be used to holistically assess sustainability in construction and building industry.

Other factors that greatly affect the selection of building materials are associated to their costs and social requirements such as thermal comfort, mechanical properties (strength and durability), aesthetic characteristics and an ability to construct quickly. Ideally, the combination of all environmental, economic and social factors can give a clear description of a material, and thus helps in a decision making process regarding the selection of the materials and its suitability (Joseph and Tretsiakova-McNally, 2010).

The main challenge, however, remain on the improvement of the productivity in end use, durability, lower maintenance, reduction of the operational energy and the reuse and recycle of materials. In recent years, governments, industrials and research and development teams have been studied and analysing alternative materials for the production of new environmentally friendly materials.

2.1.2.1. The need for Sustainable Building and Construction Materials

Construction materials and products are essential to life as we know it, regarding both buildings and infrastructure (Edwards and Bennett, 2003). Yet, construction industry is also one of the largest end users of environmental resources and one of the largest polluters of man-made and natural environments (Ding, 2008). From all direct environmental consequences of construction, the most concerning are pollution, consumption of energy and other resources (UNEP, 2003).

The results of the growing demand of selected materials and the expanding population living in finite resources affects the resource security of many countries (Allwood *et al.*, 2011). The process of mining and quarrying as well as the overall production and processing materials, have dramatic impacts on the environment accounting for considerable amount of land use. Moreover, all this processes generate a significant amount of pollution and waste, causing negative environmental impacts.

The rapid increase in the volume, the complexity of building and construction industries, and the resource demanding nature of modern technologies have been imposing severe stress on the ecosystems. According to the European Commission (EC, 2011a), the worldwide extraction of resources increased almost 50 per cent, from 40 to 58 billion tonnes, between 1980 and 2005, and is projected to increase to 100 billion tonnes by 2030. Similarly, the extensive use of fossil fuels, in the building and construction materials industries, is threatening the limited capacity of reserves and contributing to global warming. Carbon and other greenhouse gas (GHG) emissions from industries (dominated by the production of steel, cement, plastic, paper and aluminium) pose a threat to human welfare (Allwood *et al.*, 2010; Joseph and Tretsiakova-McNally, 2010; UNEP, 2010), see Figures 2.1.5 and 2.1.6. The risk of catastrophic climate change due to GHG emissions is currently seen as an urgent threat, and the basis of industrial development in its current form is challenged by the need to reduce

GHG emissions by about 85 per cent by 2050 (Joseph and Tretsiakova-McNally, 2010; Allwood *et al.*, 2011). Great amount of CO_2 is released to the atmosphere throughout the life cycle of a building, especially through its materials, construction and demolition processes, renovation, exploitation, and possible rehabilitation.

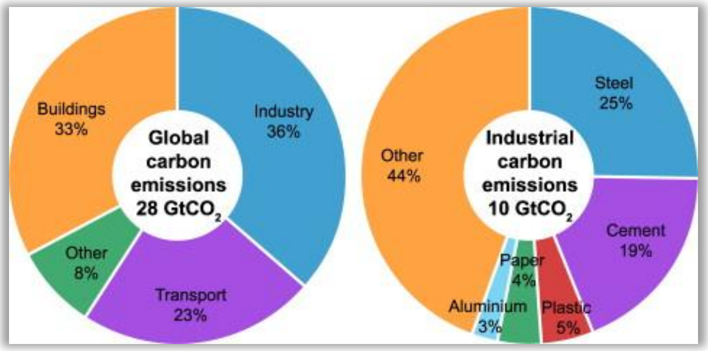

Figure 2.1.5: Global anthropogenic CO_2 emissions related to energy and industrial processes (left) for all sectors and (right) for industry. (Source: Allwood *et al.*, 2010).

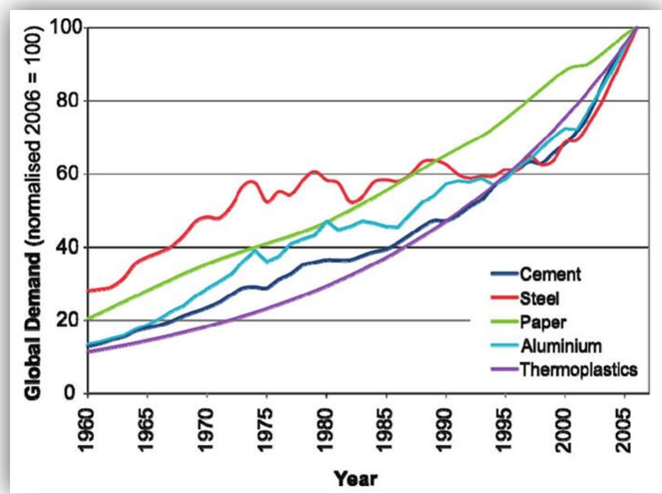

Figure 2.1.6: Construction materials demand. (Source: Allwood *et al.*, 2010).

Building and construction materials activities are intrinsically linked to the worldwide social need, which has been steadily increasing alongside the growth in population and economies (Heard et al., 2012), see Figure 2.1.7. Annually, the global consumption of building and construction industry represents 25 per cent of the wood harvest, 40 per cent of stone, sand and gravel, and 15 per cent of the water, which according Joseph and Tretsiakova-McNally (2010) accounts for 50 per cent of GHG output and 3 billion tons of raw materials being used in foundations.

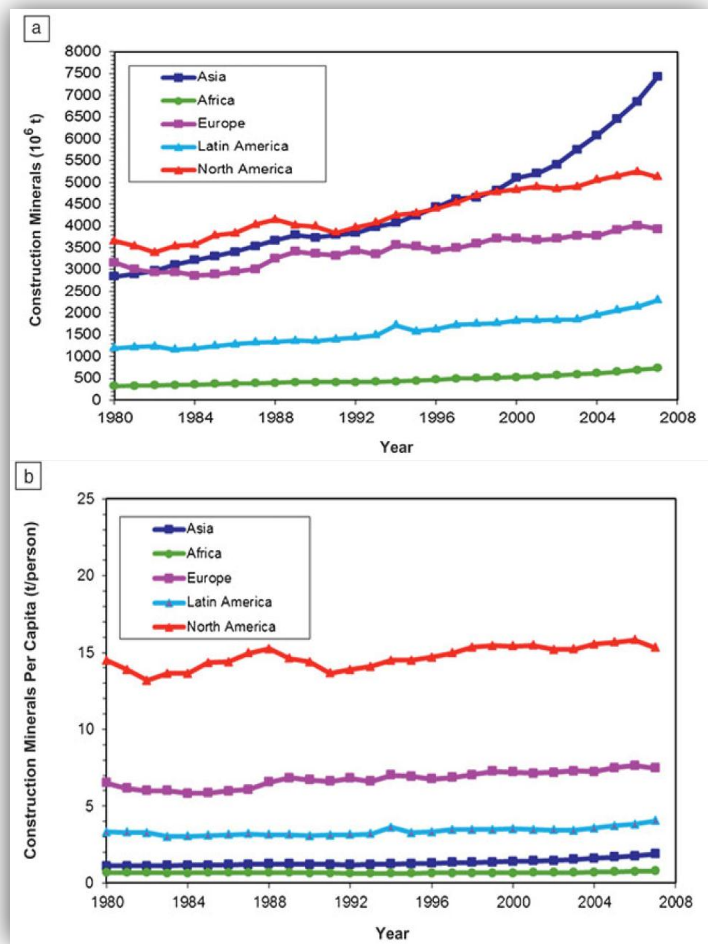

Figure 2.1.7: Magnitudes of construction minerals extraction worldwide for the period 1980-2007: (a) total and (b) per capita. (Source: Heard *et al.*, 2012).

Yuan (2012) suggests that yearly an overwhelming amount of construction waste is generated around the world, resulting in environmental and socio-economic problems that vary from country to country. Llatas (2011) supports this theory by stating that the debris from construction and demolition projects constitutes 35 per cent of solid waste in the world, which ends up in landfills. For instance, in the UK each year the construction sector alone uses 420 million tonnes of resources and converts 6,500 hectares of land from rural to urban use (EA, 2003; Lazarus, 2005a). Some authors estimate that 90 million tonnes of construction and demolition waste is generated yearly, and about 24 million of this is brick and concrete waste and from which 13 million tonnes is unused material delivered to the sites (EA, 2003; Lazarus, 2005a; DEFRA, 2011c). Similarly, according to Yuan (2012), in the US approximately 136 million tons of building related construction debris is generated every year. Furthermore, the same author suggests that in Hong Kong, the annual waste generated by construction more than doubled between 1993 and 2004, and a according to a Hong Kong's Environmental Protection Department report about 2900 tons of construction waste was received at landfills per day in 2007.

Since none of the world natural resources are infinite and only few sources of energy are sustainable, all human activities are affected by the ramification of SD (Green *et al.*, 2012). To achieve the goals of SD in building and construction a combination of factors must be considered. Most building and construction products (concrete, bricks, plastics and metals) require high amount of energy to be produced. Therefore, producers and industry face great challenges with the demand to reduce the pollution and cut down the amount of energy required for manufacturing building materials. When related to global context, building materials and components are environmentally responsible for the achievement of SD. The impact of their products should be considered over its complete life time, and classified in terms of resources use reduction, environmental impacts minimisation, and sustainable site design strategies assistance, building materials and components should pose no or very minimal environmental and human health risks (Joseph and Tretsiakova-McNally, 2010).

SD is a wide field that captures the concepts of environmental stewardship, materials management, green manufacturing, renewable and clean energy technologies, and water and air management as one. Therefore, to address SD, building materials and components should have a good recycling potential, satisfy the criteria of rational use of natural resources and energy efficiency, as well as eliminate or reduce waste generation. Moreover, building materials and components should have low toxicity, and make reasonable use and conservation of water, so to compel construction industry to develop toward the mission of sustainability.

As the global flow of materials grows with the expanding growing economy, environmental policy makers, business leaders and governments around the world are increasingly embracing energy and materials efficiency to mitigate the impacts of construction (McDonough and Braungart, 2003). In the EU the concept of SD resulted in a gradual consolidation of the legislative framework. For instance, with regard to dwelling and construction legislation was established and has been considered most likely to meet the goals with regard waste generation (Llatas, 2011). Furthermore, a strategy for 2020 was adopted aiming a resource efficient Europe and EU member states were challenged to recover 70 per cent by weight of their construction and demolition waste by 2020 (Llatas, 2011). As a result, in the UK focus was given on helping business to their resource efficiency through provision of advice, support and information, as for instance the resource efficiency delivery body, the waste and resource action programme (WRAP). In the same line EU directives on industrial policy and innovation underlines that "the world of manufacturing shall act for sustainable society", and the role of manufacturers that has been indexed to economical and technical progress for the last century, is now connected to their social and ethical consequences (Zwolinski *et al.*, 2006).

The demand for green products and greener building provides both challenges and opportunities in relation to materials usage (UKGov, 2008). In the late 20th century the paradigm "doing more with less" played a valuable role on slowing down the ecological destruction, but so far the use of less fuel to heat energy-efficient high-rises or sending less building materials to landfills does not address the full extent of the flaws of contemporary industries (McDonough and Braungart, 2003; Jackson, 2005). The challenges offered by kind of growth expected for the 21st century demand for further adoption of strategies to solve rather than remedy problems related to building and construction industries, and as different scenarios have been developed to improve the environmental value of the products at their cradle (McDonough and Braungart, 2003; Zwolinski *et al.*, 2006). The main quest resides on integrating end-of-life (EOL) properties through the life cycle in order to develop a more durable product, a product that has very little environmental impact.

In recent years a new industry that makes use of renewable and recyclable materials start to emerge. The concept of "waste equals food" became the new paradigm. The new trend regards the manufacturing building materials from the waste products of various origins. In an industrial world this refers to chemical recycling that adds value to the materials, allowing them to be used again; as a metaphor growing from this process, it suggests a strategy aimed at maximising the positive effects of materials and energy, participating in the Earth's abundant material flows (McDonough and Braungart, 2003). The use of renewable and recycled sources is widely encouraged to enhance the life cycle of the building and its elements, and as material energy and waste cost raise, environmental improvements will have greater benefits than before. According to Smith and Ball (2012) companies that have recognise the need for change and pursue more environmentally products and operations will recover costs quickly and contribute to competitive advance instead of a burden. The challenge remains in how this challenge can be achieved.

The utilization of waste products had been successfully implemented in countries like Holland and Japan, where construction industry practically lack raw materials (Joseph and

Tretsiakova-McNally, 2010). The aim is to deliver more sustainable buildings with enhanced environmental properties, through performance in use (energy consumption, thermal properties, ease of maintenance) and at EOL (how the material is recycled, recovered or disposed). However, in several studies carried out on regard the effects of materials substitutions, Thormark (2006) suggests that sometimes the energy consumption concerning low-energy housing has lower embodied energy, 40-60 per cent of the total energy use, in others, as the case of low-energy buildings, the total energy needed may be even higher than the amount of energy needed to operation. Based on the fact that large amount of energy is needed to produce and maintain technical equipment. Nevertheless, further work in this area is needed for a better understanding of the overall impacts of using such materials, from the growing and processing of the raw materials, through to the decommissioning and disposal stages (UKGov, 2008).

Meanwhile, further research has been developed around the world. Researchers use similar and different criteria to sustainably address this challenge and approach problems resulting from building and construction materials. The choice of sustainable materials can be difficult to assess, as many are the considerations to be taken into account (Mohamed, 2010). Since many and different definitions are to classify what consists an environmentally friendly or green building material, the use of waste material and/or by-products have to take into consideration the properties of the material, the evaluation tools and analyse the advantages and disadvantages of the process of recycling such waste (Mohamed, 2010). Currently, factors as embodied energy, carbon footprint or embodied carbon are also highly used in the development of new products. These parameters can provide strong methodological foundation and valuable input into policy formation, aside the fact that further advances can help design equitable and efficient climate agreements that avoid shifting problems to other administrative territories (Peters, 2010).

2.2. WASTE MANAGEMENT

The increase in the standard of living in industrialised countries has caused an increase in the number of products and services that are being produced and consumed, a factor that has been reflected in the amount of waste generated. In recent years the production and consumption of consumer goods has brought about ecological concerns with regard to disposal and recycle of waste (Guimarães *et al.*, 2009). Waste is an environmental issue, taking into account that resources are being used and thereafter thrown away, becoming waste, a process that contributes to the environmental pressures on the planet. A study developed by Beigl *et al.* (2004), with data collected along three decades (1970-2001), shows that the increase in waste generation is correlated to the long-term socio-economic trends. In the same line of thought report on municipal waste conducted by the Organisation for Economic Co-operation and Development (OECD, 2010) shows that municipal waste generation increased by approximately 65% between 1980 and 2007, in OECD countries (data excludes the Czech Republic, Hungary, Korea, Poland and Slovak Republic).

In the EU, over the last three decades, the generation and processing of municipal solid waste (MSW) has become an increasing problem in many countries, even though there has been a decrease in municipal waste generation (between 1995 and 2007), see Figure 2.2.1. From 1980 to 1995 the OECD increase on waste generation was 39.85%. Over approximately the same period of time (1995 to 2007) the OECD increase on waste generation was 18.03% which represent a slowdown on the municipal waste generation. In this figure it can also be seen that the EU municipal waste generation also suffers a slowdown in its evolution. Traditionally, the industrialised nations have dealt with their waste by sending it to landfill or by incineration, which, in both scenarios, raises significant issues and environmental threats. The conventional way of waste disposal represents a wide range of problems that result in environmental damage, meanwhile countries and communities are faced with a growing burden that is becoming harder to handle.

According to the EC (2010a), the EU produces up to 3 billion tonnes of waste every year. On average, each of the 500 million people living in the EU produces about half a tonne of MSW every year, and to this value is added the amount of waste generated from other activities, such as manufacturing (360 million tonnes), construction (900 million tonnes) and the water supply and energy sectors that generate another 95 million tonnes. According to the Department for Environment, Food and Rural Affairs (DEFRA, 2011a), in the UK, in 2008, total waste generation was estimated to be 288.6 million tonnes. The total UK waste generation has decreased by 11.3 per cent between 2004 and 2008, see Figure 2.2.2, with the industrial and commercial sector showing the biggest percentage change in waste generation, which has declined 17.3 per cent over the period. This amount of waste has a high impact on the environment and causes pollution and GHG effects, which contributes to climate change and, consequently to significant loss of materials.

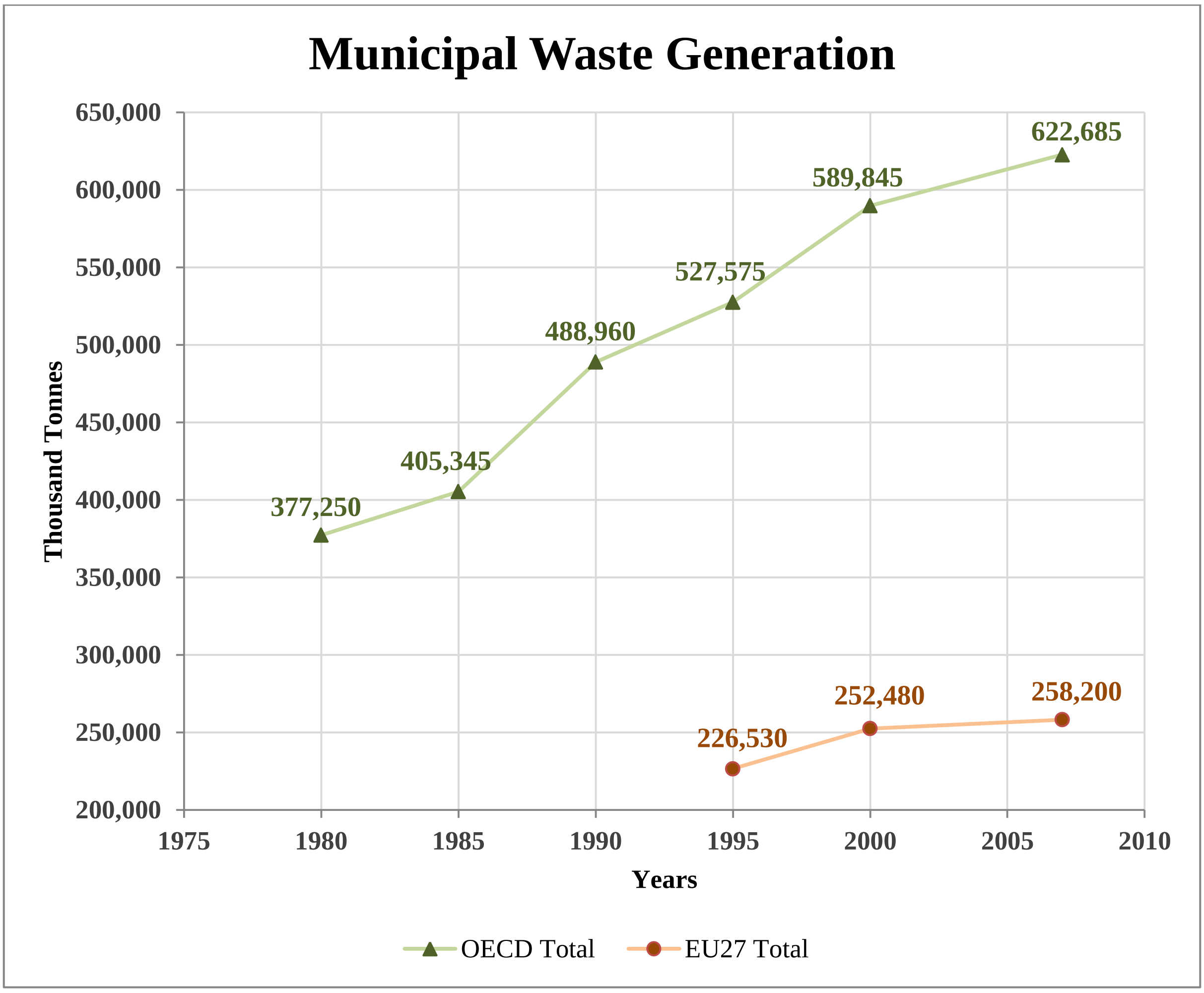

Figure 2.2.1: Evolution of the municipal waste generation in OECD countries and in Europe over the last three decades. (Source: author, with data from OECD, 2010)

In the UK, EU and worldwide, governments are trying to improve the standards of living by protecting human health, conserving the environment and making efficient use of resources, allowing the advance and long-term economic competitiveness. The aim is to implement an environmentally sound management of waste, using a pollution prevention and control system, associated to a change in consumption and production patterns, which will not only prevent the amount of waste produced but also focus on the encouragement of waste minimisation and profitability, reassuring a change for more sustainable patterns. The long-term goal is to turn Europe into a recycling society, avoiding waste and using unavoidable waste as a resource wherever possible. This goal represents a challenge seeing that the global amount of waste created is increasing at the same time that its nature is changing, partly, due to the increasingly complex mix of material compositions, which makes some plastics, and metals hazardous materials.

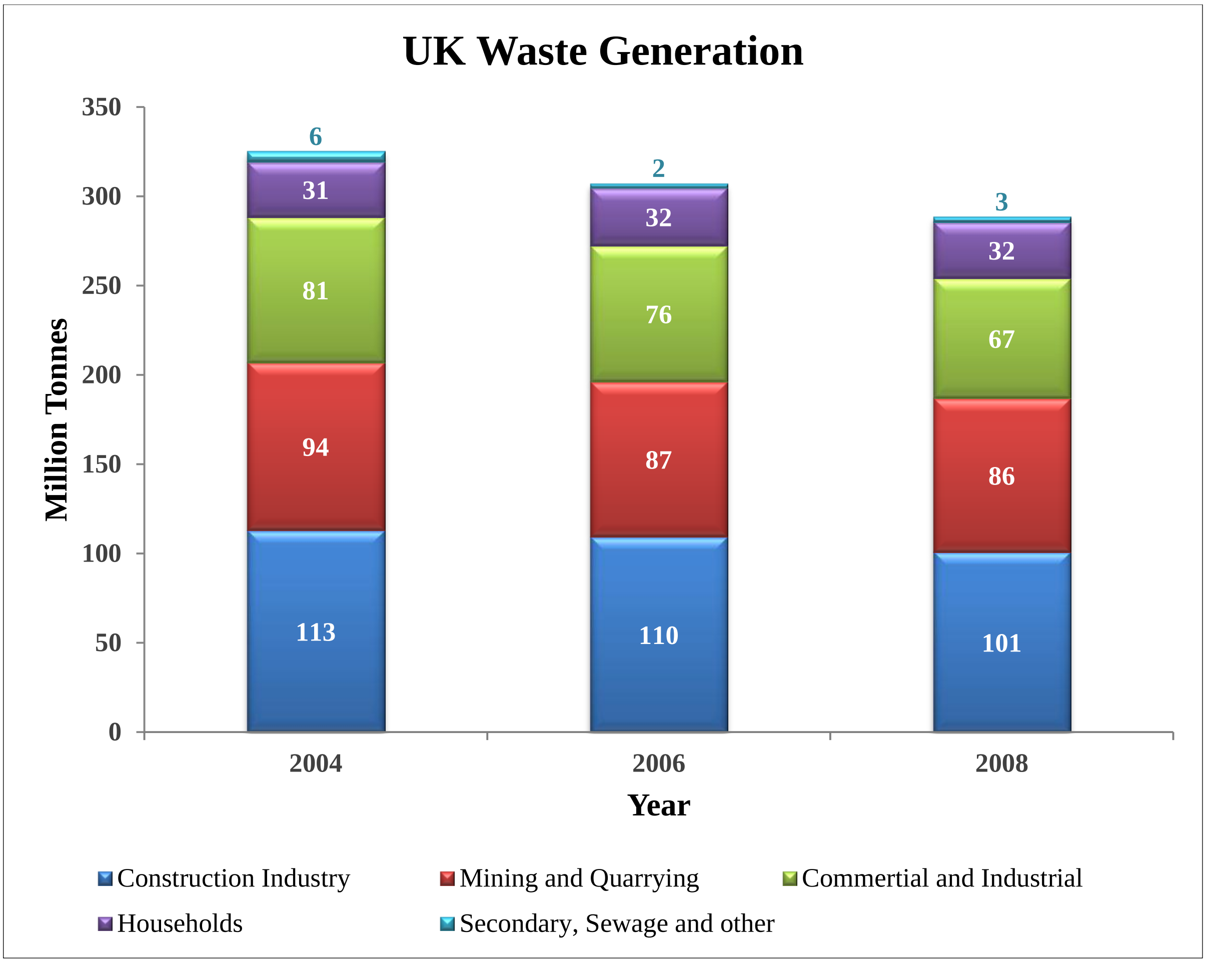

Figure 2.2.2: The figure shows the UK total waste generation between 2004 and 2008 (Source: author, with data from DEFRA, 2011a).

WM is a wide concept that involves several and different processes such as collection, transport, removal, processing, recycling, recovering, monitoring and disposal of materials considered as waste. Waste materials are generally generated due or throughout human activity and can be classified as solid, liquid, gaseous or even as hazardous. The traditional way of managing waste presupposes that waste has no value. However the current way of thinking with regard to waste assumes it as a resource for making new materials, throughout

WM approaches. An integrated WM approach considers the whole life cycle of a product and determines the best process method for it, in order to extract as much useful material as possible while saving natural and other resources. The aim is to achieve much higher levels of recycling and to minimise the extraction of additional natural resources. A proper WM strategy is a key element to ensure resource efficiency and sustainable growth of European economies.

Continually various efforts were made, on both national and international level, to institutionalize waste prevention and minimisation through the setup of legal guidelines and effective waste prevention (EN, 1975; EUR–Lex, 2008; EUR–Lex, 2006; EUR–Lex, 2004; EUR–Lex, 2002; EUR–Lex, 1999; EUR–Lex, 1994). In the UK, after the reform of the Landfill Tax Credit Scheme the government adopted strategic measures for a sustainable waste management (DEFRA, 2003), see Figure 2.2.3. Despite all the efforts made, waste disposal is still main-stream in many countries, although some countries show a shift towards energy recovery through incineration.

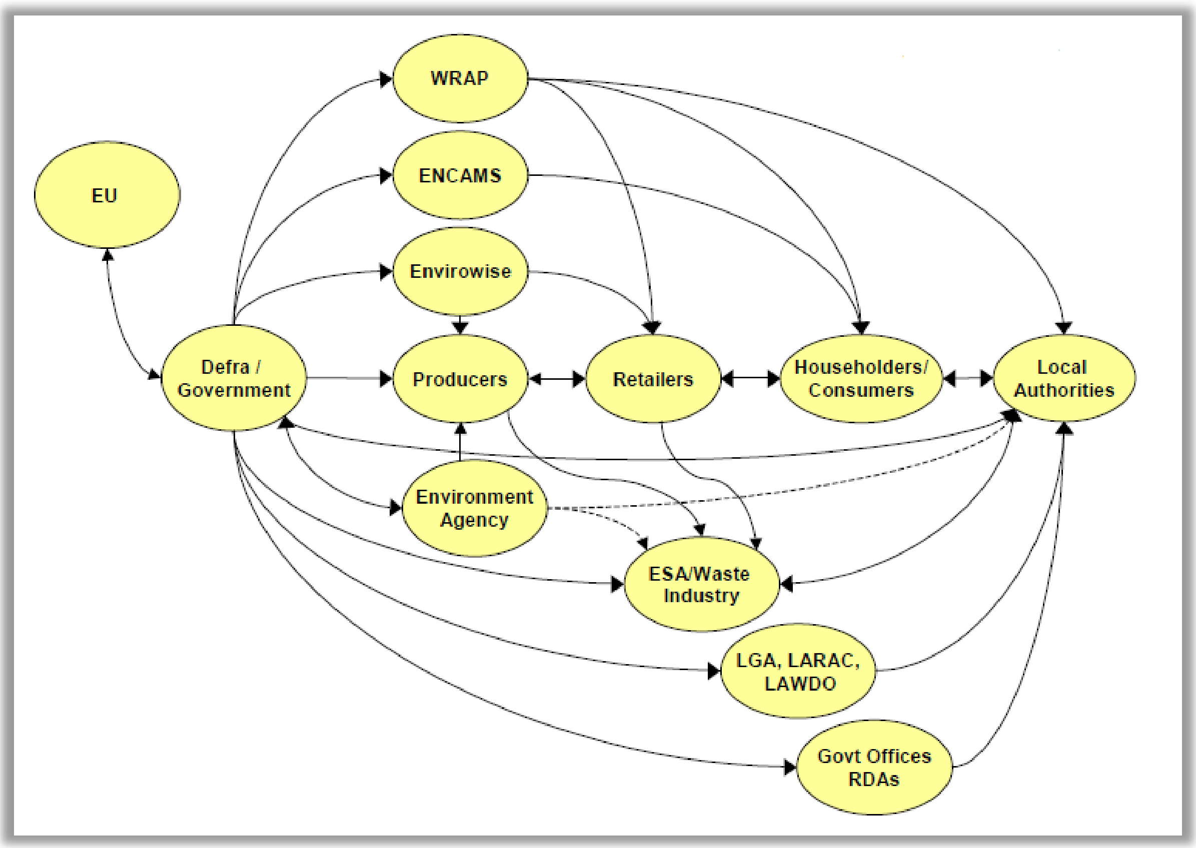

Figure 2.2.3: Delivery chain of the Waste Implementation Programme in the UK. (Source: DEFRA, 2003).

Generally, the use of materials and the waste generation are linked to the economic activities. Although different economic activities require different quantities of material input and generate different waste stream, in many projections these are assumed to be a constant ratio of economic activities (Andersen *et al.*, 2007). WM significantly differs from developed and developing countries and many developing countries are still many years away from developing proper waste management systems (WMS). Nonetheless, as the world economy grows an increased number of products are being produced and consumed which is reflected in the amount of waste generated (Salhofer *et al.*, 2008), see Figure 2.2.4.

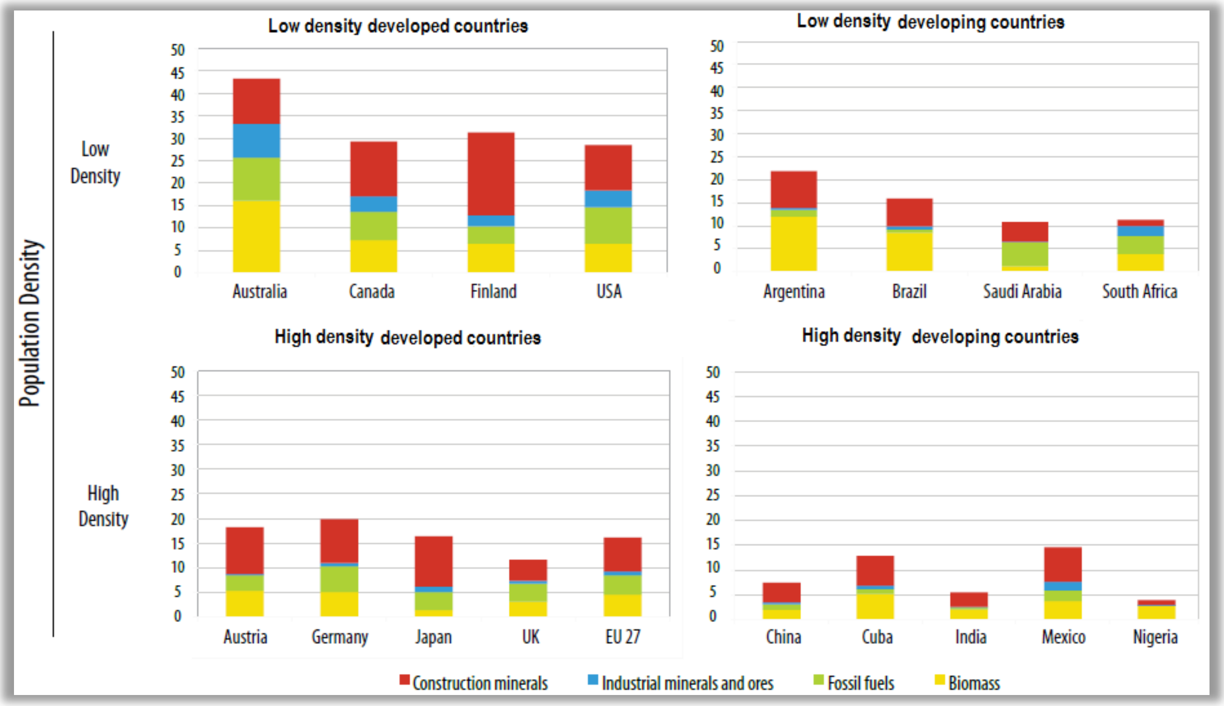

Figure 2.2.4: Domestic materials consumption by countries in 2000. (Source: UNEP, 2010).

Waste disposal affects soils, watercourses, and the air. When uncontrolled, besides the effects it has on the environment, it affects societies and economies. According to Saner *et al.* (2011), the current predominant MSW treatment option in Europe is landfilling, which claims 40 per cent share, and the number of MSW incineration plants has been constantly increasing. In the year 2008, 405 MSW incineration plants were in operation in the EU27 member states and 453 all over Europe, with an additional 43 plants planned until 2020 (Saner *et al.*, 2011). Yet, with both the stringent landfill legislation and the objectives/legislation related to ELV's treatment of various countries will limit current landfilling practice and impose an increased efficiency of the recovery and recycling (Vermeulen *et al.*, 2011).

With the increasing pressure to reduce the amount of waste disposed of in landfills, EU Directive 1999/31/EC, as well as the demands from the central government with *the landfill regulations 2004* and escalating tax payable per ton of waste disposal on landfill, it is not sustainable nor economical to carry on with traditional habits, as improper waste management cost over £200 million on landfill taxes (Seely, 2009). However, waste industry is currently in transition from a traditional one focussed on landfill disposal towards much great reuse, recycle and recovery of waste materials, and although some areas of the industry will continue to contract others have significant scope to grow.

In the UK, a recent government review of waste policy in England states that the government's aim is to decouple waste from economic growth (DEFRA, 2011c). Thus, an assessment made to waste to show the progress towards a zero waste economy measures the total amount of raw materials used and waste produced, as well as the amount of raw materials and waste produced per unit of Gross Value Added (GVA) from commercial, industrial and household, see Figure 2.2.5.

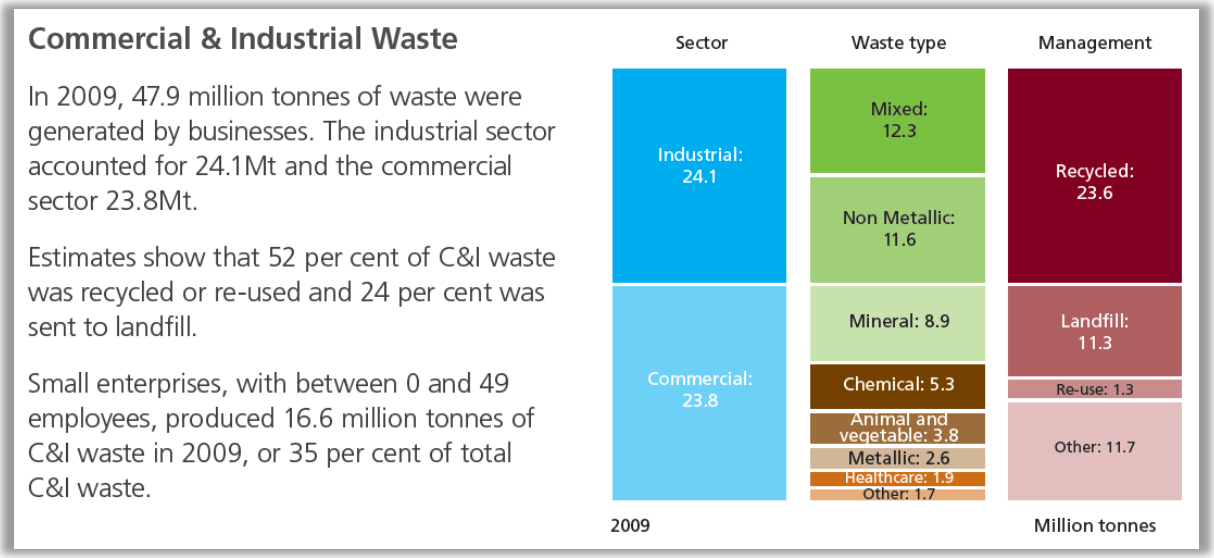

Figure 2.2.5: Recent waste statistics for commercial and industrial waste. (Source: DEFRA, 2011c).

Materials waste and the modern WMS, presents a high level of complexity due to the variety in waste streams and interdependency of the collection, recycling and disposal systems. Thus, the selection of WMS requires many aspects of the economy, society and environment to be analysed prior to the product development. In this context relevant legislation, practical guidance documents as well as creation of models and tools for sustainably manage waste are a key feature in product development and WM chain.

2.2.1. EU/UK Directives

Waste polices and subsequently WMS have their bases on the Waste Framework Derivative (WFD) of 1975 (The Council Directive 75/442/EEC), directive that lays down the first directives for waste WM and where governments settled the first appropriate actions for waste reduction. The 1975 Council Directive requested that the nine members associated to the directive applied appropriate actions to reduce certain amount of waste. Based on this directive the EU, the EC, government agencies and international organizations, have tried to establish appropriate waste policies and implement suitable legislations to establish hierarchical systems for WM, in order to reduce environmental impact under which waste prevention and minimisation were given priority. Yet, the first EU waste policies did not specify environmental emission parameters to manage waste, and as such, landfills, incineration and recycling were considered acceptable options to dispose waste, causing numerous problems involving pollution from incinerators and landfills, and even from some recycling plants.

By the end of the 1990's, after a decade of rethink economic development and find ways to halt the destruction of irreplaceable natural resources and pollution of the planet, in order to achieve SD, new environmental measures and policies were put in place. The Council Directive 1999/31/EC, on the landfill of waste, brought about a whole new range of obligatory measures associated to technical standards for waste disposal as well as its environmental standards so as to meet the expectations of the environmental standards. Under these new environmental measures and legislations for landfill waste, other important legislations and directives were also created, such as the adoption of a new EU strategy on SD, in 2001, which combined the new legislations regarding Landfill Regulations and other legislations such as the Landfill Tax.

Currently, waste policies are mainly being guided by the Sixth Environmental Action Programme 2002 (6^{th}, EAP) objectives' and its thematic strategies, which identifies natural resources and waste as one and set long-term goals for the EU. The legislative proposals associated to the thematic strategy acted as the initial movement towards adopting regulatory framework to the legal systems. The aim of 6th EAP was to ensure that the consumption of resources and their associated impacts do not exceed the carrying capacity of the environment, breaking the linkages between the economic growth and resource use; to reduce the volume of waste generated through waste prevention initiatives; to reduce the amount of waste going to landfill as well as reduce the amount of hazardous waste; and to encourage the re-use, for a better and more sustainable resource efficiency.

The 6th EAP reviews and reinforces measures and policies which set out key actions to modernise the existing legal framework, promoting sustainable production and reinforcing the vision of integrating resource, see Figure 2.2.6. However, although the perspective of resource use for sustainable production and consumption remains vital, it cannot be tackled through waste policies single-handedly. To that extent in the last decade or so it has resulted in legislations such as End-of-Life Vehicles (ELV's), packaging and packaging waste, and waste on electrical and electronic equipment (WEEE). These waste streams and practices generated in a framework legislation, see Figure 2.2.7, and other sustainable production measures such as Life Cycle Analysis (LCAs), Product Integrated WMS, Cradle-to-Cradle and Cradle-to-Grave Design, as a way to achieve the proposed targets.

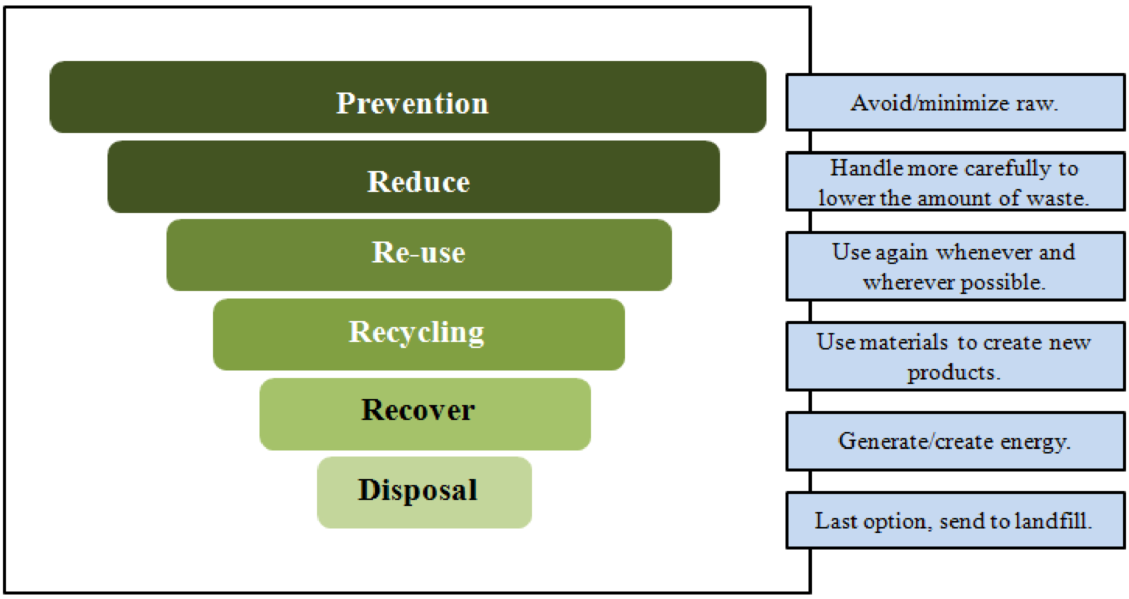

Figure 2.2.6: The current waste hierarchy which is based on resource management integration in production. (Source: author, with information provided by EC, 2005aand EC, 2005b)

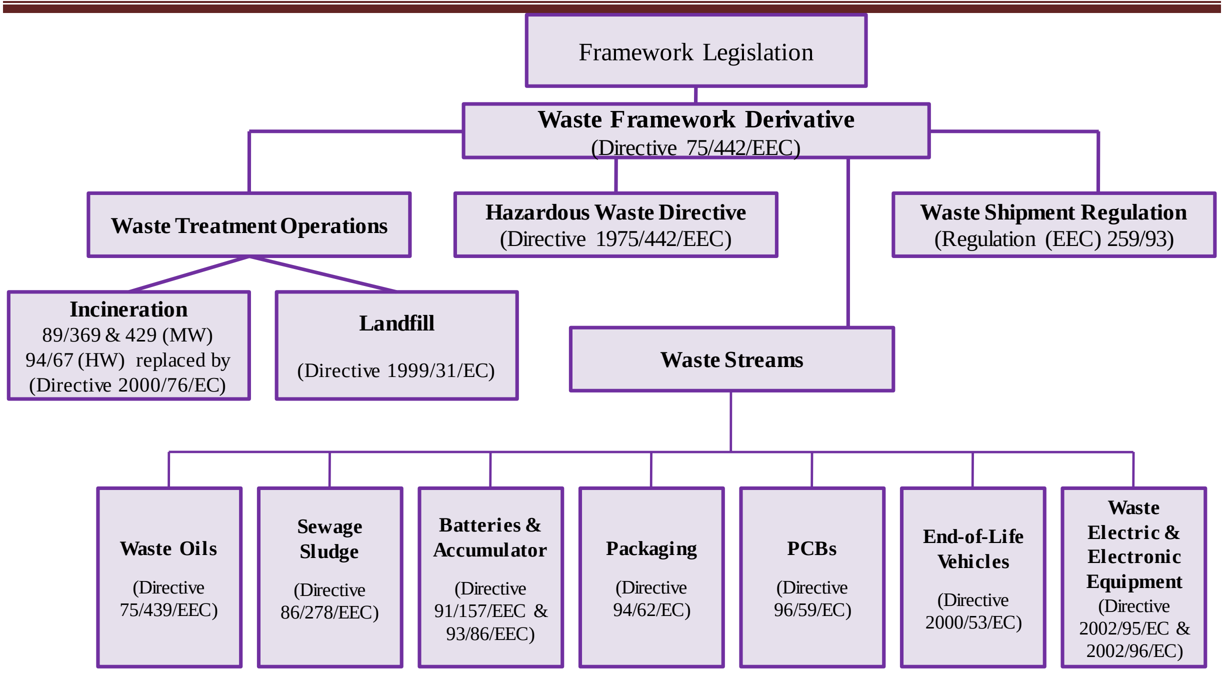

Figure 2.2.7: Waste framework legislation. (Source: author, with data from EC, 2005a)

Overall, in the last thirty years the management of waste have suffered a revolution, not only setting general principles and control procedures necessary to ensure high level of protection with regard to environmental impact across community but also due to the economics that currently is associated to waste and waste streams. In the EU waste policies and legislations are based on the principles of sustainability, prevention, producer responsibility and polluter pays, precaution, and proximity. According to the EC (2011b), the EU waste policies have so far contributed an increase in resource efficiency and in the reduction of negative environmental impacts on health and resources life cycle.

Since the implementation and enforcement of the new EU waste legislation and policies, the EC has taken continuous actions to make the legislation more cost-effective and provide the bases for sustainable growth. The introduction of Integrated Environmental Assessment (IEA), by the European Environment Agency (EEA), was the essential approach that joint different disciplines and allowed a more holistic assessment of the waste framework as well as fill gaps in the application of the WFD. For instance, according to Monkhouse and Farmer (2003), since 1990's the EU has taken a waste stream approach to identify what should be focussed on waste policy developments, aspiring to bring together relevant interests groups to participate in the decision making process, prior to the adoption of appropriate measures.

Through recent legislative measures the environmental impact of waste treatment has been reduced. This trend that is set to continue due to three of the recent adopted directives

(Council Directive1996/61/EC on *Integrated Pollution Prevention Control* (IPPC), Council Directive1999/31/EC on the *landfill of waste*, and Directive 2000/76/EC on the *incineration of waste*) that allow transitional periods for the installation existing legislations (EC, 2005a). According to the EC (2005b) the reduction on landfill waste reflects efforts made at national and international levels to achieve a common objective, allowing the WM sector to become more rigorous on its environmental standards. For instance, according to EEA (2009) report on GHG trends the EU have reduce the domestic GHG emissions by 10.7 per cent between 1990 and 2007, which could only be achieved through waste management policies (WMP) and directives. Most recent assessments show that GHG emissions from waste sector dropped 39 per cent between 1990 and 2007, and in addition to this measures, the potential use of flexible mechanisms in the period of 2013 and 2020, in line with the EU climate and energy package can help to further reduce the EU-27 GHG emission values.

The implementation of the Landfill Directive was certainly the driving force behind the development of WMP and efforts made to divert waste towards materials re-use, recycling and recover. The Landfill Directive was particularly important due to prohibitions and restrictions that came in compliance to certain type of waste and the need of treatment before disposal. Furthermore, the "end-of-waste criteria" (criteria on which after recovery waste ceases to be waste as it fulfils all the requirements to ensure that the quality of the material is such that its use is not detrimental for human health or the environment) and the strengthening of environmental standards, reinforced by IPPC policies and the incineration directive, allowed a more effective management of the waste streams (EC, 2008).

The improvement in management of waste streams has been achieved through EC directives that address certain important hazardous wastes such as batteries and waste oils. Targets of recycling and recovery were also object of reinforced policies to accomplish intended goals, and waste streams from ELV's, packaging and packaging waste, and WEEE were set to some key complex waste flows in order to separate waste streams. For instance, Bogue (2007) states that WEEE constitutes around 4 per cent of the European municipal waste, and in a period of five years the amount of waste is increasing between 16 to 28 per cent (three times faster than other municipal wastes).

Nonetheless, since its introduction the principle of producer responsibility allowed for a process related and service orientated waste policy associated to product and to consumption. Both WEEE and ELV's directives include one element of producer responsibility which encourages producers to design their products from "cradle-to-cradle" making the recycling and re-use process simpler which, in the last years, has been reflected on the design of the products (Braungart and McDonough, 2009). The fact that nowadays cars are designed to be dismantled and packaging are made of one type of plastics rather than various are reflections of the responsibility attributed to producers. The widespread use of separate collection systems has been the key to achieve the EC directives objectives attributed to waste streams, especially to EOL products, such as ELV's, packaging and WEEE, which would otherwise be aggregated to MSW streams.

2.2.2. Packaging and Plastic Recycling

The concern about the environment became more prominent in the last two decades of the 20th century. The economic growth and the change in consumption and production patterns have been resulting into a rapid increase of waste generation all over the world (UNEP, 2009). As waste generation represents an inefficient use of valuable resources, prevention and better management of waste is one of the top priorities in Europe (Eurostat, 2011). Even though the magnitude of the different waste streams varies across European countries, it is possible to identify waste streams that require specific consideration, as for example packaging waste.

According to Eurostat (2011), in 2008 an average of 164 kilograms of packaging waste (paper and cardboard, glass, plastics, wood, and metals) was produced by every EU-27 citizen, see Figure 2.2.8. Between 1998 and 2008 the total amount of packaging waste generated rose from 55 million tonnes in 1998 to 61 million tonnes in 2008, representing an increase of 9.3 per cent. Over this period of time, paper and board waste contributed for over 25 million tonnes in 1998 and over 28 million tonnes in 2008 to the total packaging waste; glass waste generation decreased from 15.1 million tonnes in 1998 to 14.7 million tonnes in 2008; and plastics packaging material increased from 9.9 million tonnes in 1998 to 13.1 million tonnes in 2008. Assessing the growth of waste generated between 1998 and 2008, see Figure 2.2.9, it can be seen that the data provided for plastics exhibits a steady growth over the decade, which may suggest that plastics will surpass glass as the second important packaging material within a few years. In the UK the packaging sector accounts for about 35 per cent of UK's plastics consumption, seeing that plastic is the elected material in nearly half of all packaged goods. Ngigi (2006) suggests that packaging represents the largest single sector of plastics use in the UK. Corroborating this information, data from Defra (2012) estimated that the UK's packaging waste was about 10.8 million tonnes in 2009, from which 47 per cent and 9 per cent represent respectively data for paper and plastic wastes.

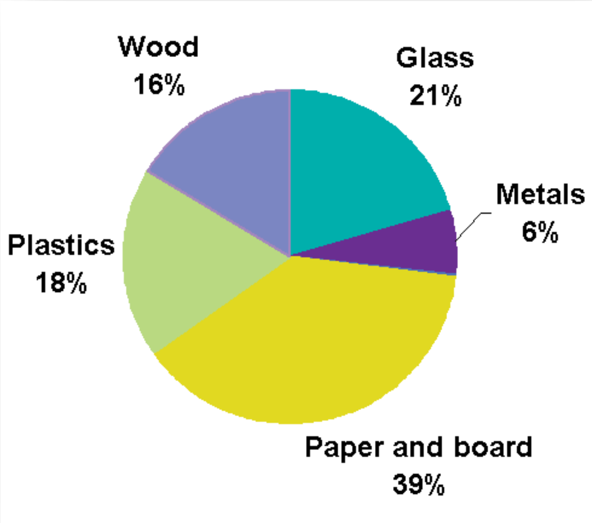

Figure 2.2.8: Shares of packaging waste by weight (Source: Eurostat, 2011)

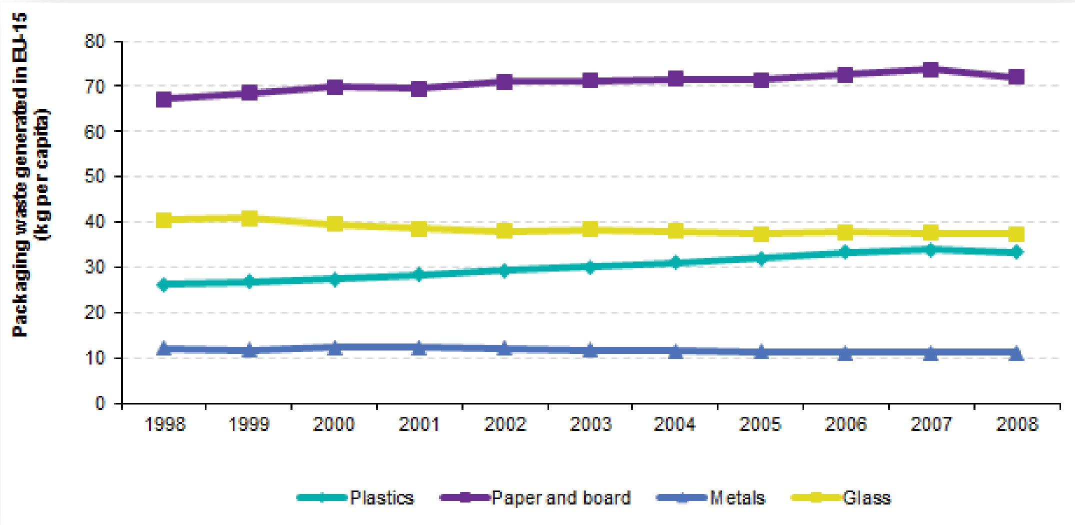

Figure 2.2.9: Development of packaging waste generated per capita between 1998 and 2008. (Source: Eurostat, 2011)

Vasudevan *et al.* (2012) suggests that from the various waste materials, plastic waste is the one of most concern, seeing that plastic consumption has increased much more than the world average due to rapid urbanization and economic development. Since 1950's the world's annual consumption of plastic materials has increased by a factor of 20, from about 5 million tonnes to nearly 100 million tonnes today (UNEP, 2009). This entails more resources being used to meet the increased demand of plastic and more plastic waste being generated. Due to the increase in its generation, plastic waste is becoming a major stream in solid waste, and even cities with low economic growth have denoted this trend on their plastic packaging waste.

This increase has turned into a major challenge for authorities and government bodies, responsible for solid waste management and sanitation seeing that finding a proper use of the disposed plastic waste is the need of the hour (Vasudevan *et al.*, 2012). To ease societal concerns over the increase amount of resources consumption and waste production, policy makers have encourage recycle and reuse strategies to reduce the demand for raw materials and decrease the quantity of waste in landfills (Guimarães *et al.*, 2009; Ross and Evans, 2003). Waste treatment prior to disposal, reduce or even prevent environmental damage. Recycling prior to waste treatment solve two problems with a single action, as it diminish the environmentally detrimental flow of waste ending in landfills and reduces the amount of scare materials being used (Eichner and Peyhing, 2001).

Although recycling is an old activity, traditionally largely determined by considerations of relative costs and appropriateness of primary and secondary resources, the quantity of packaging materials used in developed countries can still be considered very high, and as so, many new WM technologies for sorting, reutilising, recycling and/or recover plastic have been developed (Reijnders, 2000; Braunegg *et al.*, 2004). With the rapid industrialisation and economic development putting pressure on natural resources, plastic waste recycling provides an opportunity to collect and dispose of plastic waste in the most environmental friendly way, converting the waste into a resource (UNEP, 2009). According to Astrup *et al*. (2009), one tone of plastic waste collected may not substitute one tonne of virgin plastic, but from its usage about 720kg of virgin plastic is saved. In most of the situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand. Plastic waste recycling also has a great potential for resource conservation and GHG emissions reduction, such as generating diesel fuel from plastic waste.

2.3. POLYMERS

Polymers are an extremely important group on the extensive field of engineering materials. The range of properties and applications, have made polymers as broad as other major classes of materials. Their easy fabrication frequently makes it possible to produce finished items very economically, such as those for fibres, rubbers, plastics, adhesives, sealants and caulking compounds are based on polymers. For that reason, polymers have become an increasingly important as engineering material, and together with metal and ceramics, polymers represent essential engineering materials in the construction of buildings, vehicles, engines and all kind of household articles. (Halliwell, 2002; Feldman 1989)

Building and construction industry are being transformed by economic and demographic changes that are creating increased opportunities for plastic products. Due to its fast growing building and construction are second only to packaging industry in its importance as a market for polymers in Europe, accounting 20 per cent of the European plastic consumption (Chanda and Roy, 2006; Halliwell, 2002). Despite the advantages of polymers over conventional materials, including improved quality and reduction of costs, and the fact of being the fourth major class of building material used after steel, wood and cement, polymers are still represent a relatively small proportion of the total volume of building materials used (Chanda and Roy, 2006; Halliwell, 2002).

Due to its difficulty in accepting changes construction industry and construction are very cautions regarding changes and a broader acceptance of “pure” polymers and usually requires materials to have justifiable and long proven track records (Halliwell, 2002; Ashby, 2012). As so, it has not been easily to persuade building and construction sectors to switch this “new material”, although sometimes, the benefits of polymer usage are too great to be ignored (Halliwell, 2002).

Halliwell (2002) suggests that the rapid growth and evolution of polymers occurred in the last 50 years, due to the availability of basic raw materials for their production and the collective of technical properties and the reliability of the material. Theory supported by Ashby (2012) on his explanation of the polymers evolution from the mid–twentieth century and the suggestion given by him for the period in which we live now, Polymer Age.

The term polymer derives from Greek words *poly* and *meros*, meaning many/various parts (Hiemenz and Lodge, 2007). A polymeric material might be considered a substance that has a molecular structure built up primarily or completely by a covalently bonding together one or two types of repeat units with a very long chainlike molecules bonded together (Hiemenz and Lodge, 2007), see Figure 2.3.1.

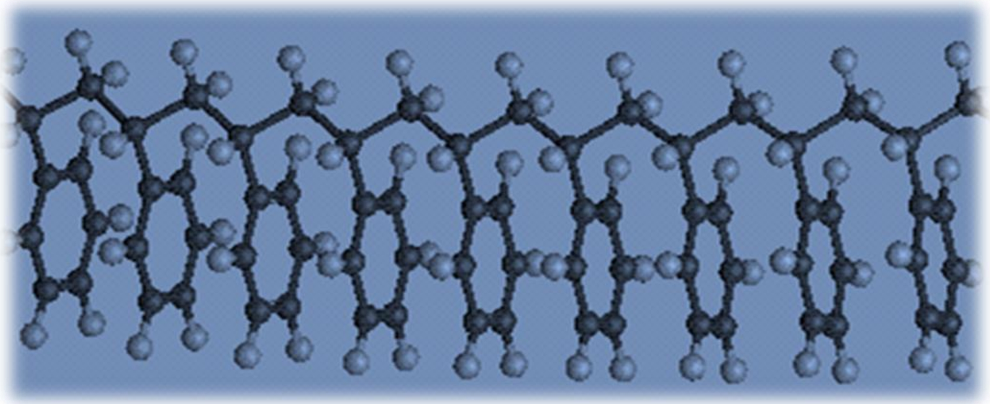

Figure 2.3.1: Isotropic Polystyrene molecular chain. (Source: *Chirality Primer*)

Polymeric materials usually vary from thin, low, viscous, liquids and soft elastic rubbers to hard, strong, solids, but they have many similarities on their fundamental structures, chemistry, physical and mechanical properties (Hiemenz and Lodge, 2007; Feldman, 1989). There are two main types of polymers materials, biological and non-biological. Biological or biopolymers derived from all living organisms since the foundation of life and provide much of the food on which man exists. Non-biological polymers are primarily the synthetic materials used for fibres, plastics, elastomers, adhesives, sealants, coatings and inorganic polymers.

Most polymers are created form engineering combination of the following elements: C, H, N and O, and are therefore classified as organic polymers. However, in some cases other elements such as Si, S, B, P, F and Cl are present in certain proportions and influence the ultimate properties of the products. Together with metals and ceramics, polymers represent the essential engineering materials for the construction of buildings, vehicles, engines, and all kind of household objects. (Hiemenz and Lodge, 2007; Feldman, 1989)

A polymer is a macromolecule build up by the repetition of small, simple chemical units called monomers; some of the simplest building units such as: ethylene, propylene, isobutylene, butadiene are by-products of the manufacture of the gasoline and luboils, and are available in large quantities. Other monomers are simple derivatives of ethylene, benzene, formaldehyde, phenol and other basic organics chemicals. The rapid growth polymeric engineering materials are due to the following main factors:

- Availability of basic raw materials for their production, which means, coal, oil, wood, agriculture and forestry wastes;
- Ensemble of technical properties specific for polymers such as light weight, chemical stability, elasticity, etc; and
- Easy processing and the knowledge of efficient procedures such as extrusion, thermal forming, injection moulding, calendaring, casting, etc.

The similarity between fibres, plastics and rubbers can most readily be seized from a consideration of structures of the macromolecules. Such structures may be extremely complicated but some generalizations are possible that aid greatly in understanding the close alliance between polymeric materials. Polymeric materials can be divided into two main types, thermoplastics and thermosetting, aside elastomers and natural polymers.

Thermoplastics

A linear polymer is normally denominated thermoplastic, which means that the chains are not cross-linked. That’s why thermoplastics are usually relatively soluble if the polymer is heated, although certain varieties show low solubility because of the extreme length of chains or the chemical groups (different from that of the solvent) attached to the chains. The molecules in linear polymers have a range of molecular weights, coupled in a variety of configurations. Some, like polystyrene are amorphous, and others, like polyethylene, are partly crystalline, representing a variety on their viscosity range of temperature.

Fibres are usually formed from this type of linear polymer. These types of polymers can repeatedly soften and melt if enough heat is applied and hardened on cooling, so that they can be converted into new plastics products. Polypropylene, polyethylene, polystyrene, polyvinyl chloride and polyvinyl chloride, among others, are example of thermoplastics, see Table 2.3.1.

Table 2.3.1: Generic thermoplastics (Source: Ashby and Jones, 2006 (p.244)).

Thermoplastic	Composition	Uses
Polyethylene, PE	$\left(\begin{matrix} & H & \\ & \vert & \\ - & C & - \\ & \vert & \\ & H & \end{matrix}\right)_n$ Partly crystalline.	Tubing, film, bottles, cups, electrical insulation, packaging.
Polypropylene, PP	$\left(\begin{matrix} & H & & H & \\ & \vert & & \vert & \\ - & C & - & C & - \\ & \vert & & \vert & \\ & H & & CH_3 & \end{matrix}\right)_n$ Partly crystalline.	Same uses as PE, but ligther, stiffer, more resistant to sunlight.
Polytetraflouroethylene, PTFE	$\left(\begin{matrix} & F & \\ & \vert & \\ - & C & - \\ & \vert & \\ & F & \end{matrix}\right)_n$ Partly crystalline	Teflon. Good, high-temperature polymer with very low friction and adhesion characteristics. Non-stick saucepans, bearings, seals.
Polystyrene, PS	$\left(\begin{matrix} & H & & H & \\ & \vert & & \vert & \\ - & C & - & C & - \\ & \vert & & \vert & \\ & H & & C_6H_5 & \end{matrix}\right)_n$ Amorphus.	Cheap moulded objcts. Toughened with butadiene to make high-impact polystyrene (HIPS). Foamed with CO_2 to make commom packaging.
Polyvinylchoride, PVC	$\left(\begin{matrix} & H & & H & \\ & \vert & & \vert & \\ - & C & - & C & - \\ & \vert & & \vert & \\ & H & & Cl & \end{matrix}\right)_n$ Amorphus.	Architectural uses (window frames, etc.). Plasticised to make arthificial leather, hoses, clothing.
Polymethylmethacrylate, PMMA	$\left(\begin{matrix} & H & & CH_3 & \\ & \vert & & \vert & \\ - & C & - & C & - \\ & \vert & & \vert & \\ & H & & COOCH_3 & \end{matrix}\right)_n$ Amorphus.	Perspex, lucite. Transparent seet and mouldings. Aircraft windows, laminated windowscreens.
Nylon 66	$(-C_6H_{11}NO-)_n$ Partly crystalline when drawn.	Textiles, rope, moulsings.

Thermosets

Thermoset or thermosetting polymers are three-dimensional polymers consisting of long chains connected up into a three-dimensional network. Thermosets are made by mixing two components (a resin and a hardener), that react and harden, at room temperature and/or on heating. The resulting polymer is generally a high frequency of cross-linking polymer. Thermoset can melt and take shape only once, and are therefore unsuitable to repeated heat treatments. The insolubility, infusibility, strength and low extensibility of thermoset polymers is usually attributed to the large number of cross-linkages (high degree of cross-linking) which make it almost impossible to separate segments of the structure. Examples of these types of polymers are phenolic resins, epoxies and polyurethanes, among others, see Table 2.3.2.

Table 2.3.2: Generic thermosets or resins (Source: Ashby and Jones, 2006 (p.245)).

Thermoset	Composition	Uses
Epoxy	$\left(-O-C_6H_4- \overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{\overset{\vert}{\underset{\vert}{C}}}} -C_6H_4-O-CH_2- \overset{\displaystyle OH}{\overset{\vert}{CH}} -CH_2- \right)_n$ Amorphus.	Fibre glass, adhesives. Expensive.
Polyester	$\left(-\overset{\displaystyle O}{\overset{\Vert}{C}}-(CH_2)_m-\overset{\displaystyle O}{\overset{\Vert}{C}}-O-\overset{\displaystyle CH_2OH}{\underset{\displaystyle CH_2OH}{\overset{\vert}{\underset{\vert}{C}}}}- \right)_n$ Amorphus.	Fibre glass, laminates. Cheaper than epoxy.
Phenol-formaldehyde	$\left(-\overset{\displaystyle OH}{\underset{\displaystyle CH_2}{\overset{\vert}{\underset{\vert}{C_6H_2}}}}-CH_2- \right)_n$ Amorphus.	Bakelite. Tufnol. Formica. Rather brittle.

The mechanical properties of polymers are of key importance in all applications where polymers are used as structural materials. Therefore the prime consideration in determining the utility of a polymer is its mechanical behaviour, that is, its deformation and flow characteristics under stress. Four important qualities characterize the stress-strain behaviour of macromolecular compound:

- Modulus: the resistance to deformation as measured by the initial stress divided by $\Delta L/L$;
- Ultimate strength or tensile strength: the stress required to rupture the sample;
- Ultimate elongation: the extent of elongation at the point where the sample ruptures; and
- Elastic elongation: the elasticity as measured by the extent of reversible elongation.

Polymers commonly vary in their mechanical behaviour depending on the degree of crystallinity, which means their macro and micro structure. Polymers are often used as protective coatings, vapour barriers, sealants caulking compounds, proof against gases and vapours; for this reason, their permeability, i.e. ability to allow gases and vapours to pass through them is a very important property. Polymers gas permeability depends both on the nature of the polymer and the nature of the gas. As the diffusion through a polymer occurs by the small molecules passing through voids and other gaps between the polymer molecules, the diffusion rate will depend on the size of the small molecules and the size of the gaps.

2.3.1. Polystyrene Foams

Worldwide the production of polystyrene corresponds to approximately 3 million tons of material per year. Packaging and consumer goods industries responsible for 54 per cent of the total production and the remaining 46 per cent is used by the construction business, where PS foams are the most used protective coatings (Schmidt *et al*, 2011).

PS is a solid transparent material, formed by the polymerization of benzene and ethylene, resultant from petroleum. Cellular polymers based on PS are generally closed cell, rigid foams that can be manufactured in densities ranging between 16 and 480 kg/m^3. The main technology processes used on the making of PS foams are moulding bead foam and extrusion.

The first type is produced from expandable PS beads, which uses a blowing agent such as hydrocarbons, halocarbons and/or mixtures of both. The expandable beads are converted to foam in stages. Initially the foams are natured and conditioned by subjecting them to heating by steam (hot water or hot air to yield pre-expanded beads). The pre-expanded beads are again heated so as to undergo additional expansion, flow to fill the spaces between particles and fuse. This produces an integral moulded item. Low density foam structures are usually made by placing pre-expanded PS beads in a mould and steaming the particles to complete the expansion process and to obtain a good bead-to-bead consolidation. (Feldman, 1989)

To produce extruded foam, a molten PS based compound containing a blowing agent is extruded at a certain temperature rage and pressure through a slit orifice to atmospheric pressure. In this condition the mass expands to about 40 times its pre-extrusion volume. Due to this the extruded board forms with a continuous surface skin or in large billets that can be cut into standard board or fabricated into desired shapes. Extruded foam has also better strength properties and higher water resistance. (Feldman, 1989)

For instance, in the production of EPS, the raw material is subjected to a process of physical transformation, without any change its chemical properties. The structure of the EPS can be observed macroscopically, where the standard structure consisting of closed balls usually with a diameter in the order of 2 to 4 millimetres (Schmidt *et al*, 2011), see Figure 2.3.2. The EPS is considered a chemically inert material not biodegradable, which means that it does not decompose, disintegrate or disappear in the environment and does not contain chlorofluorocarbons, and consequently does not chemically contaminate the environment (Schmidt *et al*, 2011). Nevertheless, EPS can be an environmental burden if not recycled, due to the fact that EPS is considered an eternal material that consumes too much space, due to its low density and high variation in size.

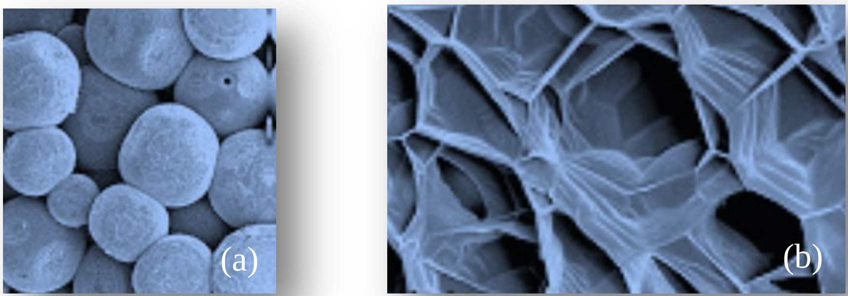

Figure 2.3.2: Observation of EPS (a) macroscopically and (b) cellular structure presented in each sphere (Source: Schmidt *et al,* 2011).

PS and PS foams have been extensively used as insulator and packaging material, accounting for more than a thousand tonnes of plastic being disposed off into the environment as MSW worldwide (Maharana *et al*., 2007). PS foams have poor outdoor weathering resistance as they resist moisture well but deteriorate when exposed to direct sunlight for long periods of time as evidence by a characteristic yellowing of the foam matrix. Multiple coats of water dispersed exterior paints will provide protection against weathering. PS foams, as others thermoplastic foams, undergo slight deterioration of their mechanical properties when the temperature is raised to the glass transition temperature, which means that different grades of PS are affected by temperatures ranging between 70 to 90^{o}C.

2.4. EXISTING RESEARCH STUDIES

The use of polymer materials in building and construction industries is not new. Since its revolution on the mid twentieth century, polymer materials have been broadly used worldwide, and, the combined annual tonnage of polymer consumption now approaches that of steel (Ashby, 2012). Polymer-based materials have been continuously used as replacement of some conventional materials and also as complementary performance enhancer for traditional material, in unique and innovative applications, to satisfy the demands of the current building and construction industries.

The use of polymeric wood-composites have been known for many years, but the costs of virgin plastic and the limited availability of appropriated wood fibre has represented, to a certain degree, a constraint for the fast development of this industry (Cui et al., 2008). Yet, the use of recycled polymer for building and construction applications is a relatively new practice. According to Climenhage (2003), during the 1990's, a number of technologies emerged to utilise recycled plastics in products designed to replace dimensional wood lumber. Since its debut, attempts have been made to recycle post-consumer plastics in order to reduce the environmental impact and consumption of virgin plastics (Adhikary et al., 2008).

Plastics are one of the main components of the global municipal solid waste (MSW) (Carroll et al., 2001; Cui et al., 2008; Climenhage, 2003). For instance, according to Adhikary et al. (2008), during 2004 plastic recovered in Western Europe accounted for 8.25 million tonnes, representing about 39 per cent of the plastic consumed, and 35,000 tonnes in New Zeland, accounting for 13.48 per cent of the total virgin plastic imported. The total European demand for recycled plastic lumbers in 2008 was estimated to be about 70.000 tonnes, which accounted for 20 to 30 per cent of urban and outdoor furniture (Passaro, 2011). Recycled plastics are cheaper than the virgin form of the material.

The use of recycled plastic lumber as resource for the production of wood substitute lumber represents a long term impact on lessening natural resource use and waste disposal. Trend stimulated by the rising volume of un-recycled waste plastic and the increasing consumer interest in more durable and lower maintenance product (Bowyer et al., 2010). Thus, the increased use of recycled plastics offers the prospect of reducing costs and minimise waste disposals. The sales of recycled plastic lumber, including pure polymer extrusions and wood-plastic composites (WPC), have grown to capture a significant share of the wood market, mainly with regards to decking boards, railings and outdoor appliances. Allen (2007) suggests that approximately 25 per cent of the three million new decks build in 2006 used composite lumber products, yet, the consumption rate of plastic lumber only accounts for a fraction of the overall softwood lumber consumption.

In the UK, EU and worldwide, there is limited research completed with regards to the of recycled polymers for applications in building and construction industry, and the most prominent researches regards to WPC were developed in the US and North America, due to the considerable growth of residential deck market (Climenhage, 2003). Plastic and WPC lumber are used in numerous applications, for both structural and non structural applications, nonetheless, the structural properties of plastic and WPC lumber are still not well understood, and its use on structural applications remains unauthorised in common building codes (Breslin et al., 1998; Carroll et al., 2010; Carroll et al., 2001; Climenhage, 2003).

One of the great advantages of plastic materials is their lightweight and the ability to be available in different colours, textures and shapes, requiring a minimal or no painting. Recycled plastic products have proven to be effective alternative for many applications, offering high durability and requiring minimal maintenance (Carroll et al., 2001; Climenhage, 2003). Plastics are resistant to heat transfer, moisture diffusion and do not suffer from root or microbial attack and can withstand weathering effects. Polymeric material and plastic composites provide unique and innovative solutions at low cost, see Figure 2.4.1 and Figure 2.4.2.

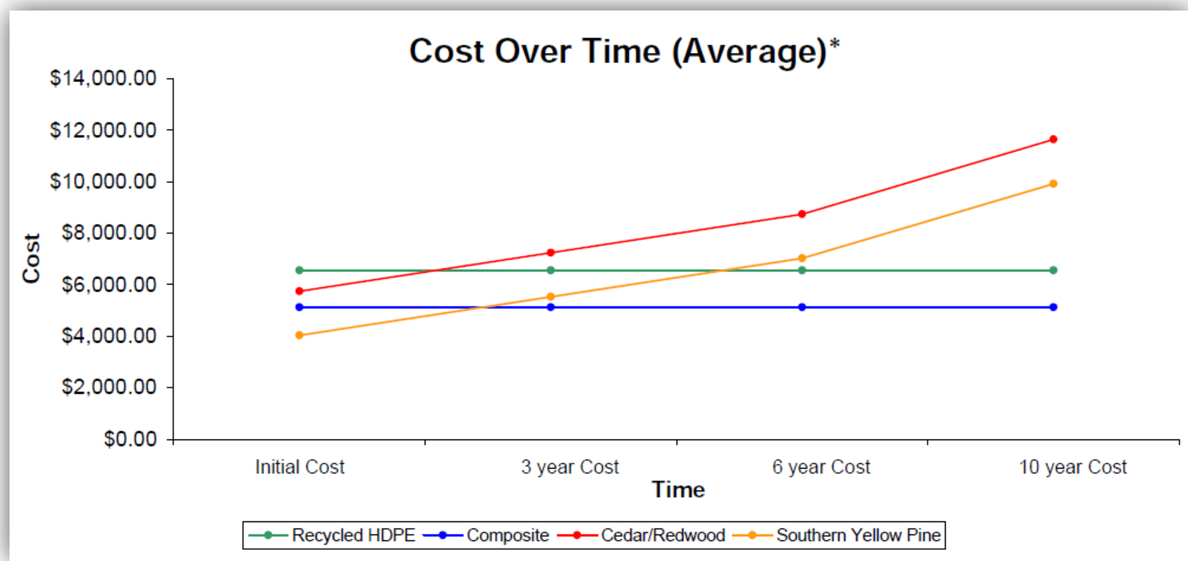

Figure 2.4.1: Decking average cost over lifetime for each of the four most common decking materials in North America, based on 2006 decking prices (Source: EPA, 2005).

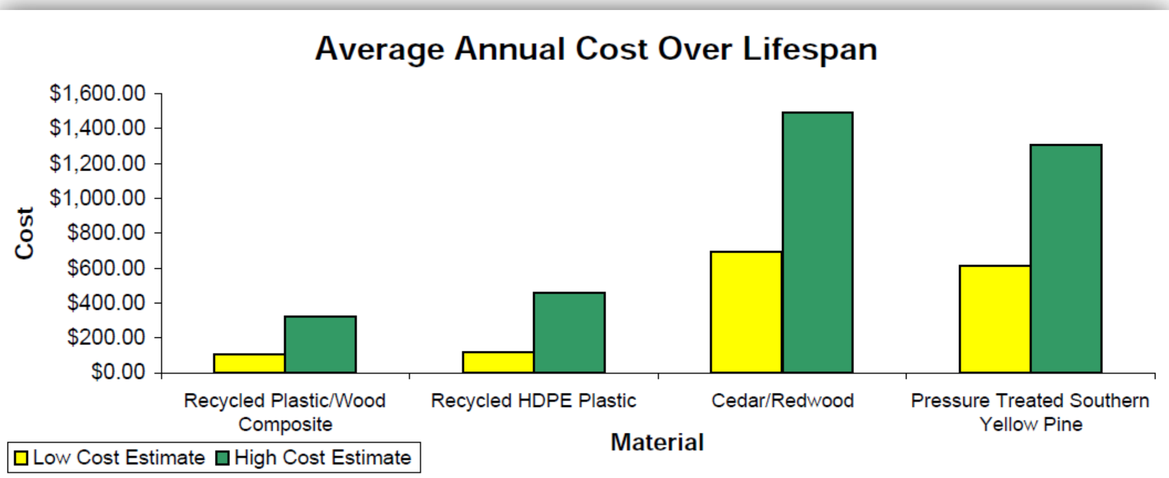

Figure 2.4.2: Estimation of decking average annual costs over lifespan for each of the four most common decking materials in North America, based on 2006 decking prices (Source: EPA, 2005).

WPC represent the fastest and largest growing segment of the plastic lumber market, one of the largest segments of the wood filled thermoplastic industry focuses on the production of WPC decking material as a replacement for preservative treated wood (Gardner and Murdoch, 2010). Notwithstanding, the combination of WPC has represented so far some uncertainties with regards to its sustainable practice. The use of mixed biological and synthetic materials represents a limited recyclability which precludes WPC of the desirable end-of-life cycle. Moreover, according to Bowyer et al. (2010) several authors have documented WPC problems regarding mould and mildew development, bio-deterioration, moisture cycling, UV degradation fading and discolouration. These issues, commonly related to wood, illustrate that the wood component in many WPCs remains susceptible to degradation, moisture uptake and loss, shrinkage and swelling, although in a smaller scale. Nonetheless, the use WCP is an exciting alternative to solid wood for many applications, especially on its lower maintenance costs, higher dimensional stability and less lumber variability (Cui et al., 2008). WPC products are relatively new and in constant development, trend that is set to continue and likely to improve along time.

In order to make a significant long-term impact on reducing resource use and disposal, it is not only important that plastic lumber include recycled content, but also that the lumber product itself be recyclable at the end-of-life cycle. Plastic lumber is an alternative to overcome the problem, and also, a sustainable incentive for a cradle-to-cradle use and manufacturing process. Plastic lumbers are largely derived from non-environmentally sound first-use applications, such as packaging, made from virgin plastic. Unless plastic lumber itself is truly efficiently used and recycled, as part of a closed-loop system of plastic products being indefinitely recycled the increase on plastic lumber market may increase waste volumes (Climenhage, 2003; Platt et al., 2005).

Designed as a safe sustainable alternative to wood, plastic lumber are durable, stable, resilient and weather-resistant, and can be worked with conventional carpentry tools and have a number of advantages over wood products (Carroll, 2001; Centriforce; Climenhage, 2003). A 100 per cent recycled polymer has added value due to its recyclability and the reduction of the consumption of raw materials and simultaneously municipal solid waste (MSW). Plastic lumber derive mainly of high and low density Polyethylene (HDPE, LDPE), Polypropylene (PP) and Polystyrene (PS), although HDPE, LDPE and PP are the most typically used, due to their high amount on feedstock (Breslin et al., 1998).

Plastic lumbers have a critical issue due to their low stiffness and low flexural strength when compared with natural wood, which foreseen limited use of plastic lumber or for structural applications. To date, most of the extruded plastic or WPC boards produced have been used for deck surfaces where the flexural modulus is less critical. In the UK, companies like British Plastic Recycling, Centriforce, Mapel and Kedel, among others, provide lumber and decking material make out of plastic, but little information is given with regards to the engineering properties of the materials.

2.5. SUMMARY

The rapid growth of the world's population and the increase in standard of living has been causing changes in the global social metabolism. The global awareness to display greater responsibility for the ecosystems on which all life depends on has led governments and industrialists to improve standards of living, and ways to make efficient use of resources. This allows for advancing and long-term economic competitiveness, factor that is only achievable through the reduction of wasteful and inefficient use of resources. This chapter has looked at sustainability and its overall role on sustainable development, sustainable construction, building and building materials. Kibert (2003) suggests that the creation and operation of a healthy built environment is based on efficiency and ecological principles. Kohler (1999) proposes that improvement can only be achieved without growth, by reducing materials throughput and improving functional quality and durability. The general agreement is that global context should be addressed to mitigate environmental impacts.

The intrinsic relation between increasing urbanisation and growth of waste generation is within the understanding of the complex interactions and feedbacks between urbanisation, materials consumption and dilapidation of resources. With the increase of environmental protection laws, the awareness of general public and the increase in costs of resources, there is a need to take into account the complete life-cycle of materials through cradle-to-cradle assessments and products integrated waste management. As so, this chapter also reviews waste management and waste stream flows (packaging and plastic recycling), as well as the EU and UK directives that allow legislation for more cost effective measures to be taken and provide the basis for sustainable growth.

Polymers are an extremely important group of materials with a broad range of properties and applications. They are, for that reason, important engineering materials, used in the construction of buildings, vehicles and all kind of household applications. The recognition of their broad use is essential for this research and was explored in this chapter, seeing that waste polymer is the material of interest on this research. The use of recycled polymer for building and construction applications is a relatively new practice. Since its first debut, attempts have been made to recycle post-consumer plastics in order to reduce the environmental impact of virgin plastic. Research was carried out on this chapter to acknowledge the existing research studies on the topic. Challenges still remain related to efficiency in use, greater reuse of materials, their durability and maintenance, but plastic and plastic composites are still a new technology and in constant development, trend that is set to continue.

CHAPTER 3

MATERIALS USED

This chapter describes the details regarding the materials used to carry out the research (material source, reasons for using each material and some physical properties). The materials used consist of three different samples of polymer decking, typical softwood blocks, and softwood and hardwood decking. The characterisation of these materials was carried out in accordance to various British Standards (BS) and other internationally accepted engineering standards, in line with UK building regulations.

3.1. POLYMER DECKING

Polymer decking is the principal material under investigation with regard to the characterisation of engineering properties of the material. The decking material is made out of expanded polystyrene (EPS) waste and was produced and provided by Styrex Limited, located in Ebbw Vale, South Wales - UK.

This material was primarily developed to replace wood boards in some building and construction applications, especially in open-air spaces, where polymer decking is presumed to withstand weathering better than wood. However, the structural properties of plastic boards are not well understood, and the use of plastic in structural applications is still being analysed in common building codes.

Although EPS is commonly known and used in building and construction industries due to its ideal characteristics (low thermal conductivity, low weight, low water absorption, and mechanical resistance), versatility and efficiency, the use of EPS waste material in building and construction is still uncommon. As the characteristics and engineering properties of recycled EPS waste used as a new product are still unknown, this research aims to establish the engineering properties of the material by testing the material so as to analyse its characteristics and feasibility to be applied in construction industry.

Material Source

EPS is widely used as packaging material, construction material, household appliances, and many others. EPS, as other plastic waste, has been causing several environmental issues due to its incapacity of being decomposed in nature (Kan and Demirboga, 2009). With the increase in the world's population and consequently the increase on consumption and production patterns, plastic waste and waste polymers have increased. Many are the plastic types being disposed on daily basis, but the type of plastic on interest for this research is the EPS.

EPS is an inert rigid cellular plastic material, without harmful chemicals that off-gas or leach during its use or disposal that can be found in a multitude of shapes and applications. Originally EPS is stable low density foam made of 98 per cent air, produced from a hydrocarbon monomer, called styrene. During the manufacturing process, the raw material is heated in pre-expanders with steam, at temperatures ranging from 80 to 100°C, resulting on a dropping of material density from about 630kg/m^3 to between 10 and 35kg/m^3 (*EPS Packaging Group*). During this process of pre-expansion the raw material's compact beads turn into cellular plastic beads with small closed cells that hold air in their interior. When cooling, the recently expanded particles from the material's beads dry simultaneously. According to the *EPS Packaging Group*, this is when the material beads achieve greater mechanical elasticity and improve expansion capacity. The last phase, moulding process, is characterised by the establishment of pre-expanded beads which are transported to moulds and subjected to steam again so that the beads bind together. This is the way moulded shapes or large blocks are obtained.

Prior to its manufacturing process the EPS waste material is collected from different sources and converted into a hard polystyrene block of the compacted EPS, for an easy transportation, see Figure 3.1.1. The process of manufacturing of the new product starts when the waste EPS arrives to the recycling unit and the waste polymer is crushed into shredder. The process of manufacturing of the polymer decking is shown in Figure 3.1.2. EPS foam waste loses its foam characteristics as part of the remanufacturing process. Once in the factory, the material is, in a first stage, cut into small pieces and then filtered to remove impurities see Figure 3.1.2 (a). In the next stage the material is re-melted and cooled, which results in the increase of the material density. The material is afterwards involved in preservatives and colour admixtures, before being re-melted again and moulded to its final shape. In this last stage the material is extruded into a mould shape and cooled in water, see Figure 3.1. 2 (b, c, d).

Figure 3.1.1: Compacted EPS block.

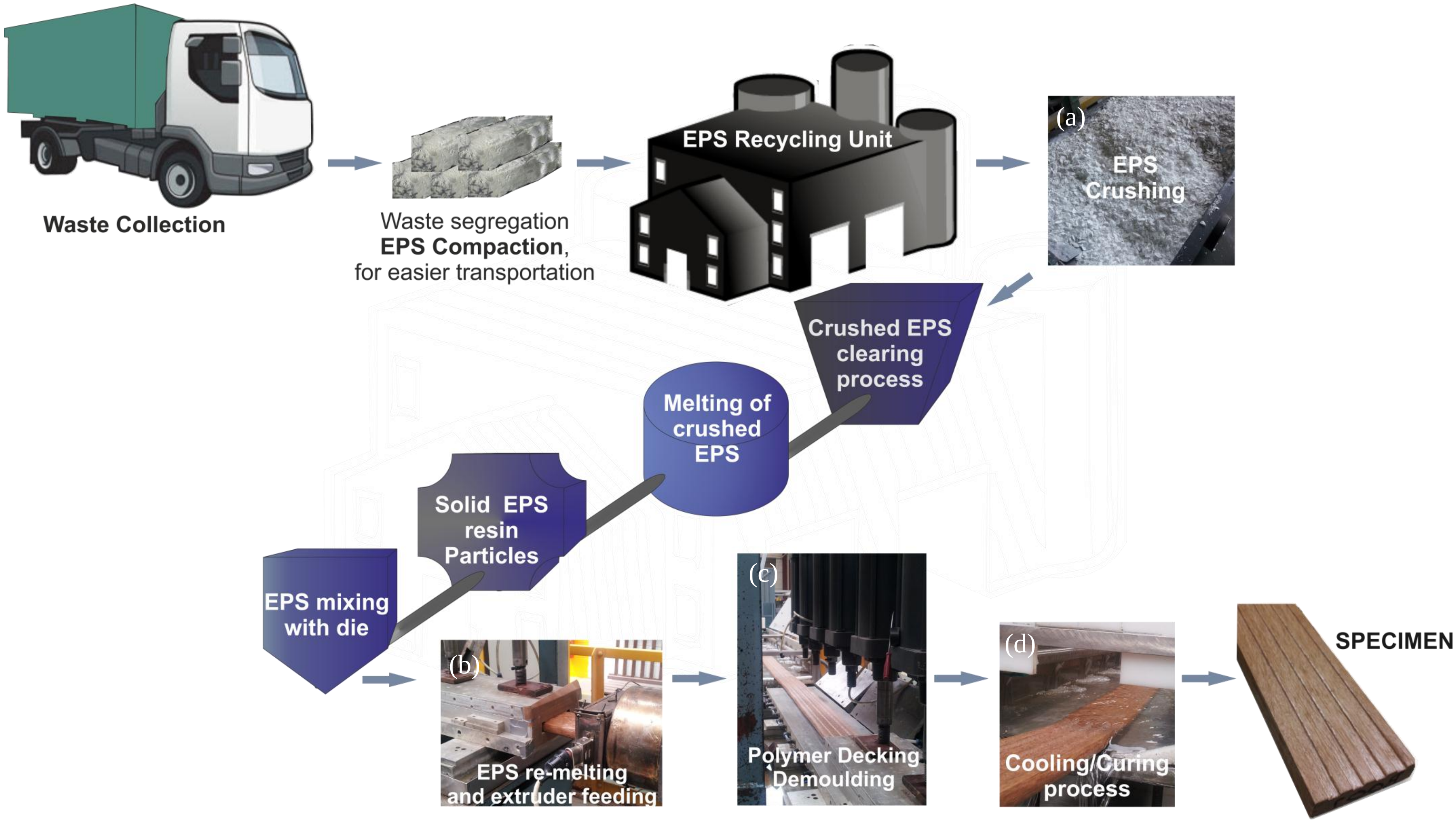

Figure 3.1.2: Polymer decking manufacturing process. Pieces of EPS before being filtered for manufacturing process (a), polymer decking extrusion (b), moulding (c), and cooling (d) process.

The polymer decking boards are produced as reversible deck board, flat on one side, grooved on the other, and with the following specifications:

- 3000mm length;
- 124mm width;
- 25mm thickness; and
- Brown colour.

Figure 3.1.3: Polymer decking board.

3.2. TYPICAL SOFT WOOD

Wood is one of the oldest and best-known structural materials which our society depends on for a variety type of uses. Wood is a natural, heterogeneous, anisotropic, hygroscopic composite material. Due to a whole range of physical and mechanical properties, wood species can be selected on the basis of how well they perform for the required product. Its structural properties are highly variable and so influencing factors must be taken into consideration with regard to the structural properties of the wood.

The use of typical soft wood (TSW) was considered in this research in order to provide comparative data analysis for the characterisation of the polymer decking. The TWS used to carry out of this study was ordinary wood, pre-existent in the engineering laboratories.

3.3. WOOD DECKING

After the initial use of TSW for comparative analysis, wood decking material was considered for use in this research to provide more thorough comparative data for the analysis of the results obtained from the polymer decking characterisation.

The data obtained from the polymer decking characterisation was to be compared to the values of softwood and hardwood decking material due to the distinctive characteristics of each type of wood, see Table 3.3.1. Both wood decking used to carry out this work (softwood and hardwood) were purchased in B&Q and their specifications are stated below and were provided by the vendor.

Table 3.3.1: Characteristics of softwood and hardwood

	Hardwood	Softwood
Origin	Deciduous trees that drop their leaves every year.	Conifer trees have needles, normally do not lose them.
Usages	Used for trimmings and furniture but less frequently than softwood.	Widely used as wood ware for building (homes/cabins) and furniture
Types	Mahogany, teak, walnut, oak, ash, elm, aspen, poplar, birch, maple, red grandis, etc.	Pine, spruce, cedar, fir, larch, douglas-fir etc.
Cost	Usually the most expensive	Cheap, when compared to hardwood.
Growth	Hardwood has a slower growth rate.	Softwood has a faster rate of growth.
Properties	Broad leaves; enclosed nuts; higher density (not all hardwood is hard e.g. poplar and basswood).	Less dense; less durable; high calorific values.
Type	Mostly deciduous. Some evergreen (holly, boxwood and holm oak)	Evergreen.
Density	High density and usually harder.	Low density, most varieties are softer than hardwood.
Shedding of leaves	Shed their leaves over a period of time	Tend to keep leaves throughout the year.
Colour	Dark	Light
Annular ring	Not Distinct	Distinct
Weight	Heavy	Light
Strength	Strong in compression, tension and shear(strong along and across the grains)	Strong in tension but weak in shear(strong along the grains)
Structure	Non - resinous and close grained	Resinous and splits easy
Fire Resistance	More	Poor

3.3.1. Softwood

The softwood decking (SWD) is a reversible board, flat one side and ribbed on the other made out of Norwegian Spruce, see Figure 3.3.1. According to the supplier specifications the wood board is pressured and treated with a copper-based wood preservative, giving it a distinctive greenish tone, and with the following specifications:

- 4800mm length;
- 144mm width; and
- 28mm thickness.

Figure 3.3.1: Softwood decking board.

3.3.2. Hardwood

The hardwood decking (HWD) is a reversible board, flat in on side and ribbed on the other made out of Red Grandis, see Figure 3.3.2. According to the supplier this distinctive red-hardwood deck board is gently ridged with a natural and with the following specifications:

- 2350mm length;
- 120mm width; and
- 19mm thickness.

Figure 3.3.2: Hardwood decking board.

CHAPTER 4

EXPERIMENTAL PROCEDURES

This Chapter describes the methods and analytical techniques used to carry out the work. Tests for engineering parameters, such as density, water absorption, compressive strength, flexural strength, thermal conductivity, freezing and thawing, effects of weathering and ultraviolet (UV) light, bonding, and shrinkage and swelling are described on this chapter.

4.1. SPECIMENS PREPARATION

Before any test could be carried out, all samples of each specimen were cut, measured, weighed and labelled and the details were recorded, see Figure 4.1.1. Beside the polymer decking samples, which have the same dimensions overall, the samples used to carry out the various tests have variations on their width and thickness, as they were provided from distinctive sources. All samples were kept with their original thickness and width dimensions and only the length was standardised to the same dimensions of the polymer decking samples. Although samples from the same source and composition were expected to express equal weight and to be of the same volume and density, there were usually small variations, therefore, the samples used for these experimental procedures were assumed to present small variations, especially due to the fact that they were cut manually.

In order to carry out each of the tests, three samples of each specimen material were used. A standard length of 150 millimetres was used for the majority of the tests with the exception of compressive and flexural strength tests, and wet freeze-thaw tests. With regard to compressive and flexural tests the dimension of the samples was based on the thickness ratio of the specimens in analysis. Small cubes of about $25 \times 25 \times 25mm$ were used for the compressive strength tests and small planks of about $0.5m$ were used for the flexural strength tests, see Figure 4.5.1. With respect to wet freeze-thaw tests the sizes of the small blocks shown in Figure 5.6.3 and 5.6.4 were dependent on the size of the metal containers in which they were placed in during the tests. At this stage the specimens' spatial orientation was also defined, see Figure 4.1.2.

Figure 4.1.1: Samples preparation, measurement of samples (a) length, (b) width and (c) thickness.

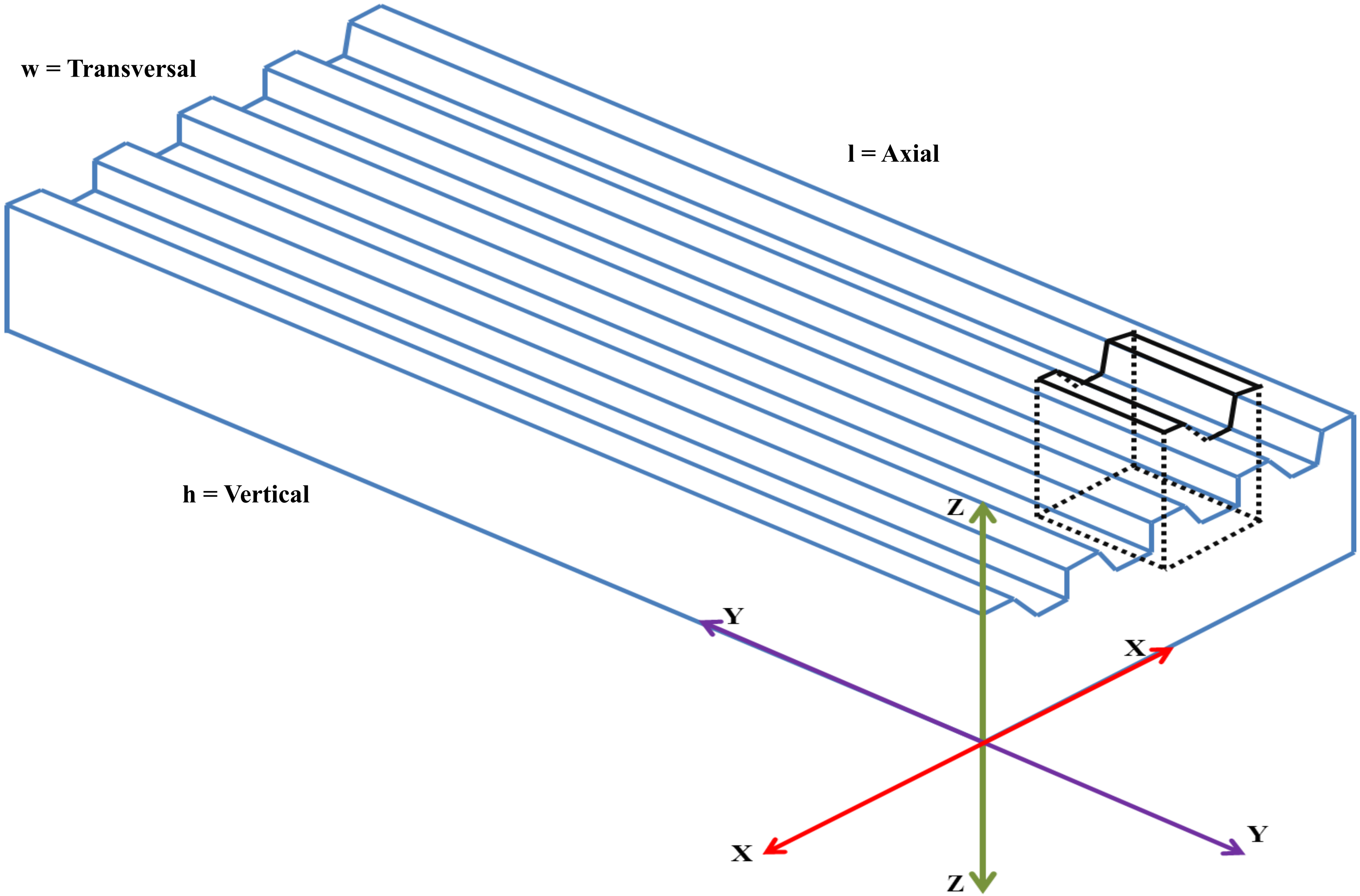

Figure 4.1.2: Schematics of samples block orientation and cube section.

4.2. DENSITY

The density of a material is its mass per unit volume. The mass density of a material varies with temperature and pressure. Different materials usually have different densities, and this is intrinsically related to temperature, pressure, buoyancy and purity of materials among other factors. Increasing the pressure on an object decreases the volume of the object and therefore increases its density.

The volume can be measured using the linear measurements methods or by weighing, submerging the material in the water, or even by displacement of water. A less dense fluid floats on more dense fluids if they do not mix. This concept can be applied to less dense solids floating on more dense liquids. If the average density of a material is less than the water density (1000kg/m^3) it will float and if the density is higher the material will sink.

Density can be expressed in terms of bulk, dry and saturated density. The bulk density of a material is the mass per unit volume of the material including any moisture content that the material contains. It includes the solid volume as well as any voids space.

Bulk density is needed for converting moisture content percentage by weight to content by volume, so as to calculate porosity and voids ratio when the particle density is known. The bulk density is an important parameter to characterize the changes for a given material.

Apparatus

- Polymer decking (B001, B002, B003) $150mm \times 124mm \times 25mm$
- Typical softwood block (TSW) $150mm \times 100mm \times 48mm$
- Hardwood decking (HWD) $150mm \times 145mm \times 22mm$
- Softwood decking (SWD) $150mm \times 141mm \times 26mm$
- 1 Steel plate $101mm \times 128mm \times 15mm$
- Digital Vernier Callipers
- Water tank
- Electronic scale
- Single range (electro-magnetic force compensation / load cell / strain gauge) weighing machine (31 to 0.001kN resolution)

Methodology

The density test was carried out by means of the water displacement test, determined under guidance and in accordance to BS EN 12390 – 7: 2009. This experimental test procedure required the use a steel plate to sink the sample. As so the steel plate was measured and weight and all details were recorded. All specimens were cut, trimmed and labelled before being measured with a digital vernier callipers and the weight recorded from the electronic scale. The steel plate used for this experimental procedure served as a standard equipment to provide adequate weight for sinking the samples. The steel plate was also measured and its weight was recorded.

Three samples of each specimen were subject to the density test. Initially, the polymer decking (B001), first batch to be delivered for testing, was compared to a laboratory pre-existing TSW. The density measurements for these two specimens were carried out daily, over a period of twenty days. The other two polymer batches (B002 and B003) were delivered for testing at different timescales and presented different weight from each other and from the batch received initially, and so their density was measured separately. The wood decking (SWD and HWD) was purchased for comparative analysis purposes, and as so their densities were also measured.

During the experiment each specimen was placed in the suspended stirrup beneath the balance mechanism of the Single Range weighing machine with the steel plate on top. Each specimen was lowered to the water tank and the values recorded, see Figures 4.2.1 and 4.2.2. The measurement of the densities of B002, B003, SWD and HWD were measured on day 1, 7, 14, 28, 56 and 90. The densities of B001 and TSW were also measured within these parameters. The volume and mass of the samples were determined, and the density calculated using the following equation:

$Density\ (\rho) = \frac{M_S}{V_S} = kg/m^3$ ....Equation 1

Where:

$M_S = Mass\ of\ the\ specimen$

$V_S = Volume\ of\ the\ specimen$

Figure 4.2.1: Polymer block B001 density testing.

Figure 4.2.2: TSW block density testing.

4.3. WATER ABSORPTION

The rate of water absorption of a specimen is determined by the incremental mass change measurements, over a relative period of time of immersion in cold water. In this laboratory procedure three samples of each batch were subjected to tests and the mean percentage of water absorption determined. This experiment was determined in accordance with BS EN 771-1: 2011.

Apparatus

- Polymer decking (B001, B002, B003) $150mm \times 124mm \times 25mm$
- Typical softwood block (TSW) $150mm \times 100mm \times 48mm$
- Hardwood decking (HWD) $150mm \times 145mm \times 22mm$
- Softwood decking (SWD) $150mm \times 141mm \times 26mm$
- 1 Steel plate $101mm \times 128mm \times 15mm$
- Digital Vernier Callipers
- Water tank
- Electronic scale
- Single Range (electro-magnetic force compensation / load cell / strain gauge) weighing machine (31 to 0.001kN resolution)

Methodology

For the initial laboratory experiment the samples were placed in a water tank with the capacity to submerge them at a 20ºC room temperature, see Figure 4.3.1. The change in mass was measured immediately after submersion for specimens B001 and TSW, and then daily measurements were made in the following first 18 days. Thereafter, next the readings were taken after a soaking period of the 53 and 91 days. In a subsequent laboratory experiment the change in mass was determined immediately after submersion for specimens B001, B002, B003, then after readings were taken after a total soaking period of 7, 14, 28, 56 and 90 days. With regard to HWD and SWD readings, a late start on the testing programme of these samples and the interruption for Christmas holidays resulted on the lack of data for day 56. The data collected from the specimens' samples correspond to a total soaking period of 7, 14, 28 and 90 days. All specimens used for this test are the same used for the determination of the density. Prior to the test the samples were cut, trimmed, labelled, weight with an electronic scale and measured with a digital vernier callipers. In order to carry out of this experiment a steel plate was required to sink the samples. The steel plate was measured and weight and all details recorded to provide adequate data for the determination of the rate of water absorption (see Appendix C). Each specimen was placed in the suspended stirrup beneath the balance mechanism of the Single Range weighing machine. Each sample was mechanically lowered to the water tank and the values recorded. The rate of water absorption of the samples, percentage by mass, was calculated from the following equation:

$$Rate\ of\ water\ absorptin\ (W_w) = \frac{M_w - M_D}{M_D} \times 100\%$$ ....Equation 2

Where:

$M_D\ =\ Mass\ of\ the\ specimen\ before\ soak$

$M_w\ =\ Mass\ of\ the\ specimen\ after\ being\ removed\ from\ the\ water\ tank$

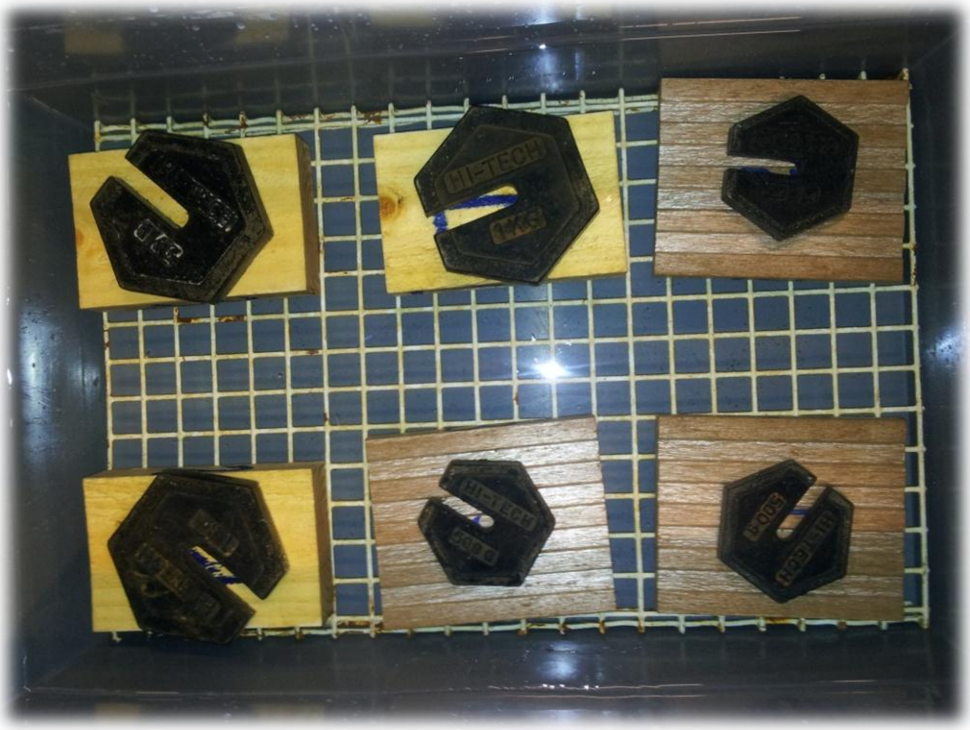

Figure 4.3.1: Polymer block B001 and TSW block immersion in cold water at room temperature, 20ºC.

4.4. UNCONFINED COMPRESSIVE STRENGTH (UCS)

The strength of a material is defined as the maximum load (stress) that the material can carry. Compressive strength tests are a common engineering test for the purpose of specification and quality control. Prior to carrying out this experiment, all samples were measured and the data recorded for calculation of the unit area where the load was to be applied, see Figure 4.4.1. The unconfined compressive strength (UCS) test of the specimens was determined using an Instron 8502 testing machine ranging from 250 to 0.001kN, see Figure 4.4.2.

Before the start of testing, the end surfaces of all specimens were examined to ensure a flat surface and good contact with the top and bottom steel plates. The load was applied in the samples by means of load control method, through a hydraulic actuator that measured the response of the samples via a load cell. These tests were carried out at two different set of loads, 10kN and 20kN increment per minute. An average 24 cubes was used per specimen type and four cubes were used in each set. The compressive strength of each cube was determined from its peak failure load. All data was recorded for each cube and a mean value calculated.

Figure 4.4.1: Measurement of the dimensions of the cubes specimens.

Figure 4.4.2: Using Instron 8502 testing machine for the determination of the UCS.

Apparatus

- Polymer decking (B001, B002, B003) $27mm \times 27mm \times 25mm$
- Hardwood decking (HWD) $26mm \times 28mm \times 22mm$
- Softwood decking (SWD) $27mm \times 31mm \times 26mm$
- Digital Vernier Callipers
- Instron 8502 (250 to 0.001kN resolution)

Methodology

In order to carry out this experiment, cubes of the specimens were placed at the centre of the steel plate. The cubes were loaded in the three spatial orientations so as to define the strongest surface under compression load, see Figure 4.4.3. The tests were determined under guidance of BS 1881-121: 1983, BS EN 771-1: 2011 and BS EN 772-1: 2011, using a 250kN capacity Instron 8502 testing machine. The load was applied continuously, using the load control method at a steady rate of 0.167kN/s for the 10kN per minute, and a rate of 0.333kN/s for the 20kN per minute. The compressive strength can be determined from the following equations:

$f_c = \frac{F_c}{A_c} = N/mm^2$ ....Equation 3

$Stress\ (\sigma) = \frac{F}{A} = N/mm^2$ ....Equation 4

$Strain\ (\varepsilon) = \frac{\Delta L}{L}$ ....Equation 5

$Modulus\ Elasticity\ in\ compression(E_c) = \frac{\sigma}{\varepsilon} = N/mm^2$ ....Equation 6

Where:

$F_c = Maximum\ load\ at\ failure\ (N)$

$A_c = Area\ of\ the\ cube\ (mm^2)$

$\Delta L = Change\ in\ length(mm)$

$L\ (h) = Length\ (mm)$

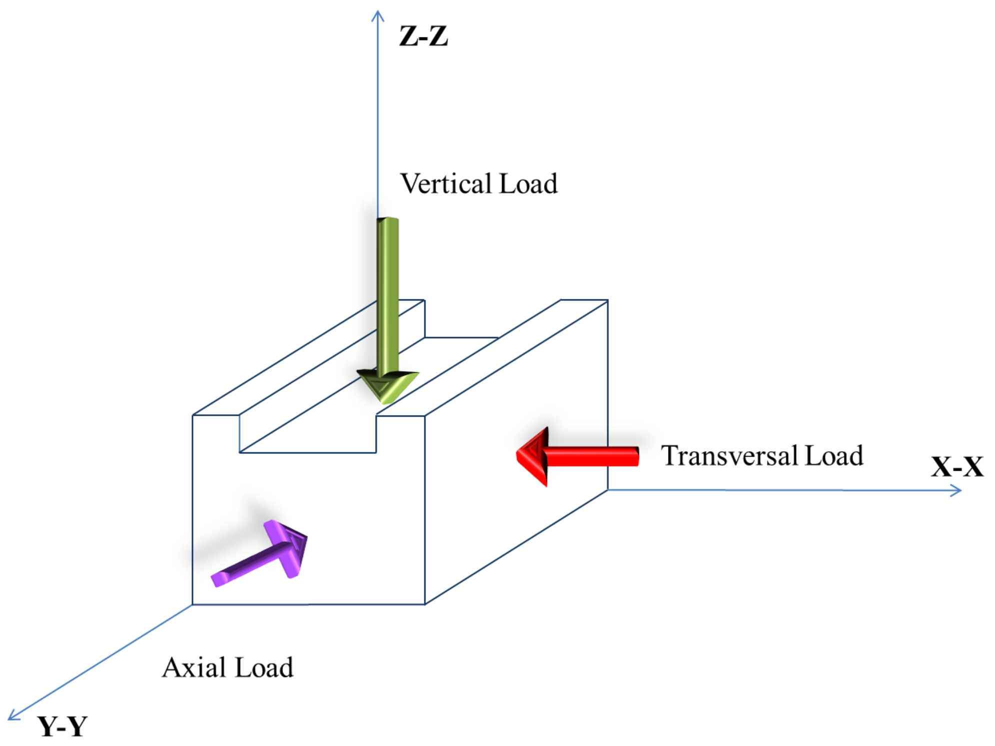

Figure 4.4.3: Schematics of the spatial orientation of the cubes specimens.

4.5. FLEXURAL STRENGTH

Flexural strength is defined as the material ability to withstand deformation under load. Flexural strength tests are common engineering tests to specify the bending strength and elasticity of a material, as flexural strength represents the highest stress experienced within the material at its rupture moment.

Apparatus

- Polymer decking (B001) $525mm \times 124mm \times 25mm$
- Softwood decking (SWD) $546mm \times 141mm \times 26mm$
- Measuring tape
- Dial Gauge
- Dartec Universal Actuator (50 to 0.2kN resolution)

Methodology

In order to carry out of this experiment, small planks of the specimens were marked for the location of the supporting pins and load points. Supports were prepared and allocated with regard to the board length and overhang space. Prior to carrying out of this experiment, small planks of B001 and SWD samples were cut and measured in accordance to BS EN 408: 2010 + A1: 2012, see Figure 4.5.1. The experimental flexural strength test of the specimens was determined using a Dartec Universal Actuator testing machine ranging from 50 to 5kN in tension (0.2kN resolution), Figure 4.5.2. Three samples of each specimen were tested in this experiment. The bending strength was then recorded mechanically and manually and the flexural strength of each board was determined from the experiment peak failure load, see Figure 4.5.3. All data were recorded from each board and a mean value calculated afterwards. The flexural strength can be determined with the following equation:

$f_m = \frac{3F_a}{bh^2} = N/mm^2$ ....Equation 7

Where:

$$F_m = Bending\ strength\ (N/mm^2)$$

$$F = Load\ \ (N)$$

$$a\ =\ Distance\ between\ a\ loading\ position\ and\ the\ neareast\ support\ (mm)$$

$$b = Width\ \ of\ the\ cross - section\ (mm)$$

$$h = Depth\ of\ the\ cross - section\ (mm)$$

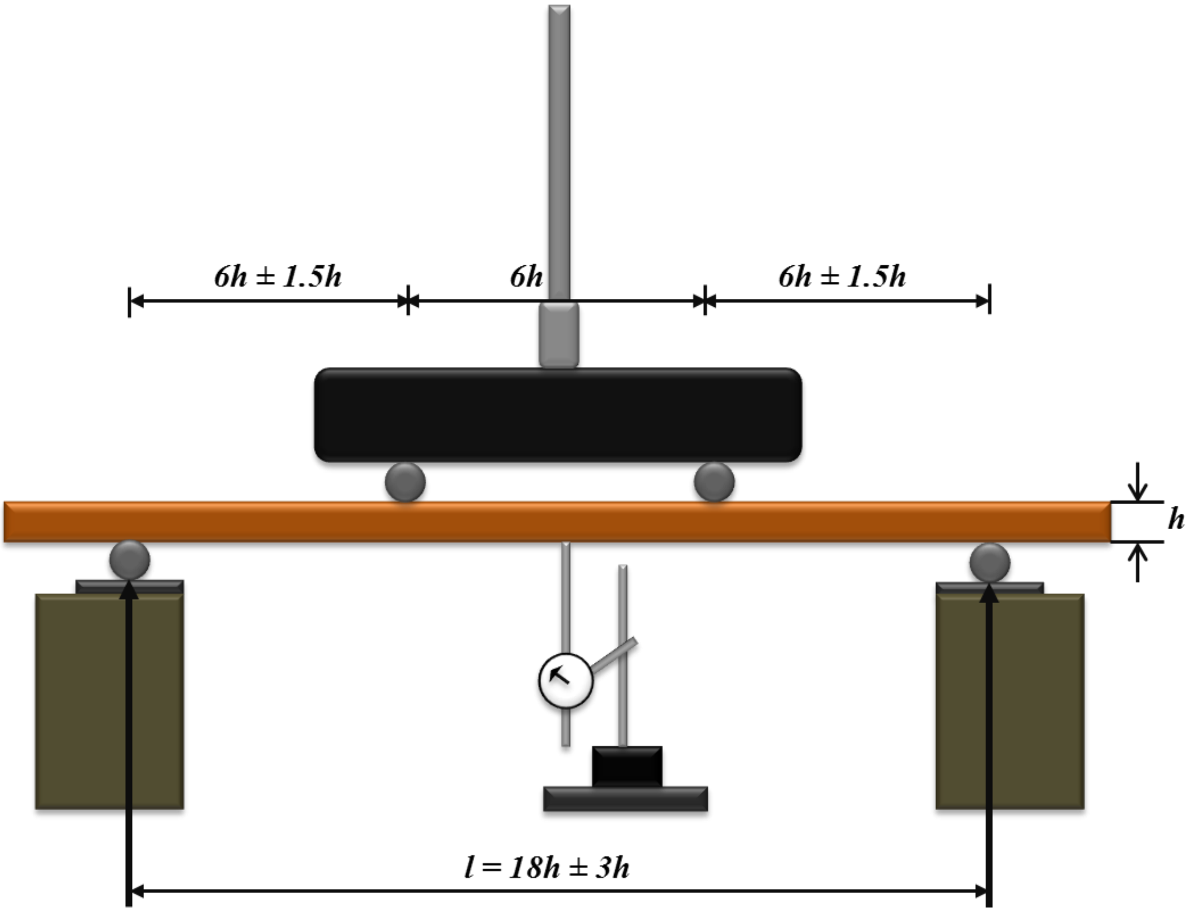

Figure 4.5.1: Schematics of the test arrangements for measuring flexural strength.

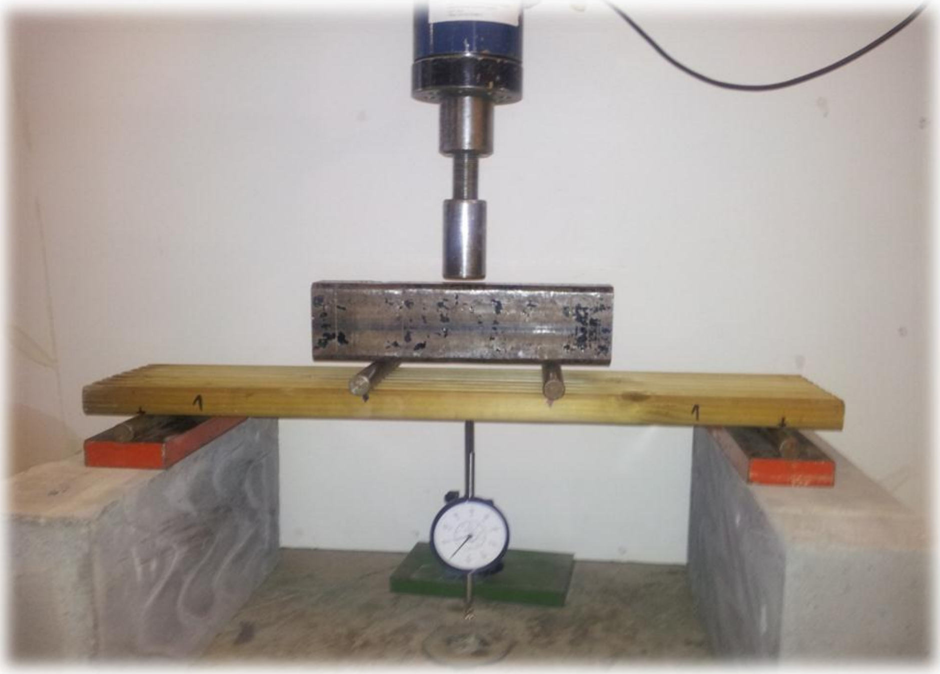

Figure 4.5.2: SWD (1) flexural test on a Dartec Universal Actuator equipment.

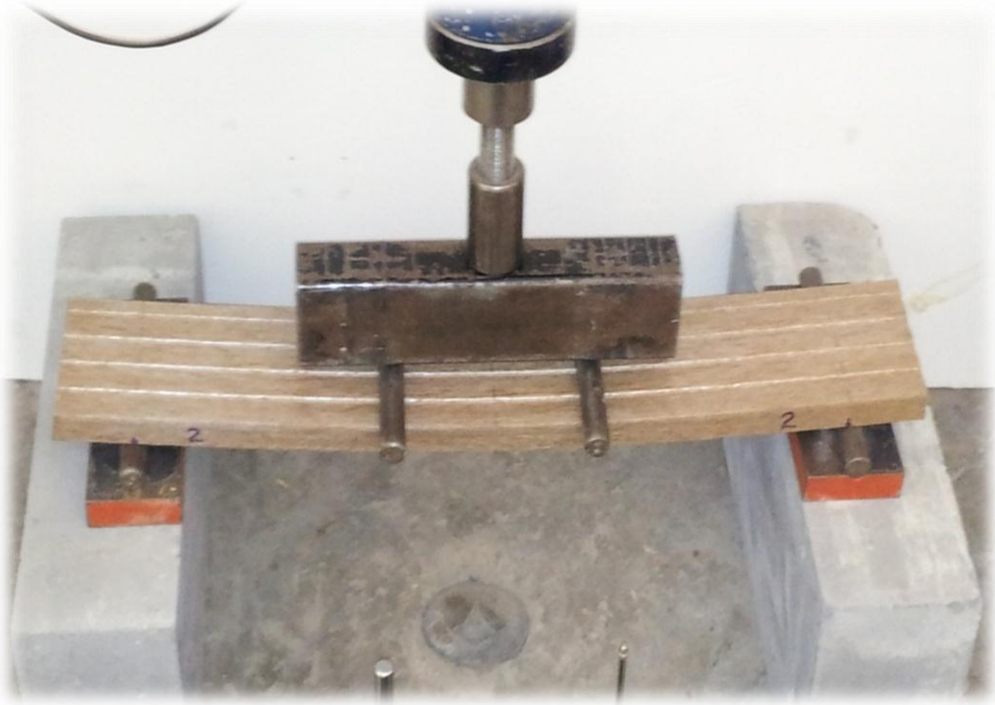

Figure 4.5.3: B001 (2) flexural test on a Dartec Universal Actuator equipment.

4.6. THERMAL CONDUCTIVITY

Thermal conductivity is usually expressed as the property of a material to conduct heat. Conduction is defined as the mode of heat transfer in which energy exchange takes place from the region of high temperature to that of low temperature by the kinetic motion or direct impact of molecules. Thermal conductivity tests are governed by the empirical law of heat, that states that the rate of heat flow by conduction in a given direction is proportional to the area normal to the direction of heat flow and to the gradient of temperature in that direction. According to Fourier-Biot law, this means that the temperature gradient is proportional of the rate of heat flow.

Thermal conductivity measures the rate of heat flow through one unit thickness of a material subjected to a temperature gradient. Therefore, the thermal conductivity of the specimens was determined using the measured lower and upper lambda limits. A Laser-Comp FOX 200 thermal conductivity meter equipped with WinTherm32 software was used for the collection of the laboratory data, see Figure 4.6.1. The thermal conductivity equipment is in compliance with BS EN 1745: 2012, designed according to ASTM C518 – 91 and calibrated in accordance to ASTM C1132 – 89. The specifications for the thermal conductivity equipment can be seen in Table 4.6.1.

The equipment was designed to test steady-state heat flux measurements and thermal transmission properties by means of a heat flow meter. The inner part of the equipment has a stationary upper plate and a movable lower plate, both with flat surfaces. Each surface has a transducer that monitors and controls the thermal conductivity (λ). The actual measuring area for the equipment plate to measure the temperature is the square central area of the plate (76 mm^2).The principle of the heat flow meter is based on one-dimensional Fourier- Biot law, which considers:

$$q = -\lambda\left(\frac{dT}{dx}\right) \qquad \text{Equation 8}$$

Where:

$q = Heat\ Flux\ (W/m^2)$

$\lambda = Thermal\ Conductivity\ (Wm^{-1}K^{-1})$

$\frac{dT}{dx} = Temperature\ Gradient\ (Km^{-1})$

$\Delta T = Temp_{hot} - Temp_{cold}$

$\Delta X = Specimen\ Thickness$

Figure 4.6.1: Thermal conductivity equipment Laser-Comp FOX 200 with WinTherm32 software (a) and polymer decking test specimen inside equipment.

Table 4.6.1: Thermal conductivity equipment specifications

Description	Specifications
Maximum specimen size	203 mm x 203 mm x 51 mm
Temperature Range	-20ºC to 95ºC
Absolute accuracy	± 1%
Reproducibility	± 0.5%
Repeatability	± 0.2%
Thickness measurement accuracy	± 0.025mm
Temperature control stability	± 0.03ºC
Maximum temperature of hot plate	75ºC
Maximum temperature of cold plate	-20ºC
Conductivity Range	0.0050 – 0.6012W/mK
Conductance	Max. $12W/m^2$

Apparatus

- Polymer decking (B001, B002, B003) $150mm \times 124mm \times 25mm$
- Typical softwood block (TSW) $150mm \times 100mm \times 48mm$
- Hardwood decking (HWD) $150mm \times 145mm \times 22mm$
- Softwood decking (SWD) $150mm \times 141mm \times 26mm$
- Digital Vernier Callipers
- Laser-Comp FOX 200
- Laser-Comp FOX 50

Methodology

Prior to the tests, the specimens were cut measured and weighed. The equipment was set out for eight measurements of thermal conductivity as shown in Table 4.6.2. The settings were selected at different temperature range to stimulate exposure conditions of the materials to different temperatures. Due to unforeseen problems with the equipment further tests had to be carried out externally, by Gearing Scientific Ltd, in Ashwell Herts, UK.

The tests carried out internally, using Laser-Comp Fox 200, used 8 different temperature set-points, with 25˚C difference between plates. Due to the various set-points and the increase in temperature of the upper and lower plates throughout the test, the mean temperature of the tests carried out internally varies and ranges from -7.5˚C to +62.5˚C within a range of about 15hours per tested sample.

Contrariwise, the procedure used by Gearing Scientific Ltd for the carry out the tests uses a single temperature set-point, with 20˚C difference between plates. The mean temperature of 20ºC results from the difference in temperature of a 30ºC upper plate and 10ºC in the lower plate of the Laser-Comp FOX 50 apparatus. The centre of each plate had a 25mm^2 heat flux transducer and thermocouple embedded. The samples were cut in octagons of 50 to 60 millimetres diameter. The tests carried out externally were recorded every 128 seconds, for the last 2 minutes of measurement recorded. The average reading of the samples was recorded after about one hour of equilibrium.

Table 4.6.2: Thermal conductivity temperature settings

Test N.	Lower Plate Temperature (T_L)ºC	Upper Plate Temperature (T_U)ºC	Difference in Temperature ºC	Mean Temperature ºC
1	-20	5	25	-7.5
2	-10	15	25	2.5
3	0	25	25	12.5
4	10	35	25	22.5
5	20	45	25	32.5
6	30	55	25	42.5
7	40	65	25	52.5
8	50	75	25	62.5

4.7. FREEZING and THAWING

Construction material should be sufficiently durable to resist local exposure conditions so as to maintain the structural and operational integrity. Therefore, it is necessary to assess the likely degree of exposure to which units are to be subjected, including the protection against saturation of the construction material. The type of exposure (severe, moderate, and passive) shows the behaviour of the material when exposed to weather variations.

The freeze-thaw testing was performed in a Prior Clave LCH/600/25 model 0.7m^3 volume capacity environmental chamber, see Figure 4.7.1. These tests were carried out under guidance of BS EN 772-18: 2011, CEN/TR 15177: 2006 and DD CEN/TS 12390-9: 2006. The testing apparatus consisted of a climatic chamber with continuous 24 hours freeze-thaw cycles, maintained between -15˚C and +30˚C for 24 hours in a 28 days cycle. Both dry and wet freeze-thaw tests were adopted for this study, modified from the above concrete-based standards, in order to determine the freeze and thaw properties of the specimens.

Apparatus

- Polymer decking (B001, B002, B003) $150mm \times 124mm \times 25mm$
- Polymer decking (B001, B002, B003) wet $100mm \times 124mm \times 25mm$
- Typical softwood block (TSW) $150mm \times 100mm \times 48mm$
- Hardwood decking (HWD) $150mm \times 145mm \times 22mm$
- Hardwood decking (HWD) wet $100mm \times 145mm \times 22mm$
- Softwood decking (SWD) $150mm \times 141mm \times 26mm$
- Softwood decking (SWD) wet $100mm \times 141mm \times 26mm$
- Steel container
- Digital Vernier Callipers
- Electronic scale
- Prior Clave LCH/600/25

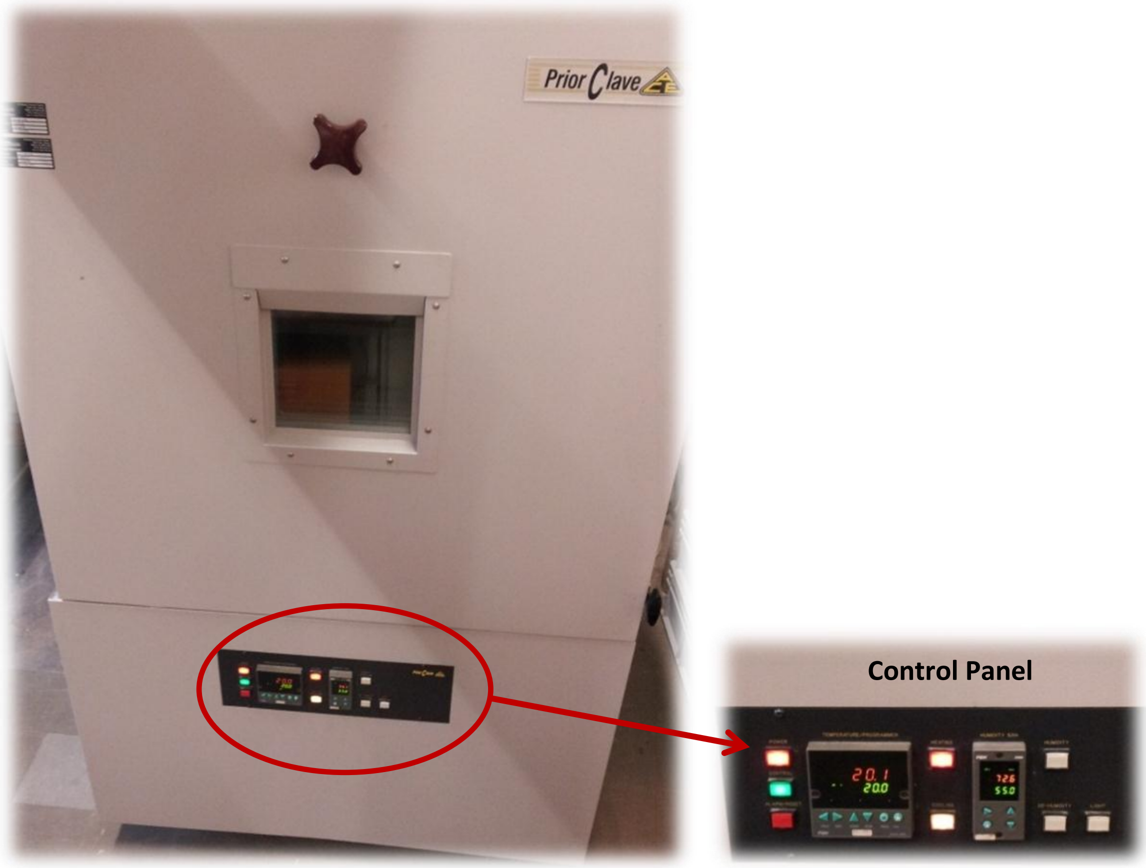

Figure 4.7.1: Prior Clave environmental chamber, used for freeze-thaw measurement.

Methodology

Prior to the tests, the specimens were cut measured and weighed. Samples of each specimen were wrapped in cling film placed in the chamber for the dry freeze-thaw test, including samples that were subjected to long term water submersion and were still wet. Smaller samples of each specimen, shortened in length, were placed individually in a steel container, submerged in water. The equipment was then set out for the 24 hours freeze-thaw cycle, shown in Table 4.7.1. The 24 hours temperature profile started at 20˚C, went up to 30˚C and stayed there for 3hours. Started descending to -15˚C in a four hours' time lap. After achieving -15˚C stayed there for 10 hours, and finally started a six hours temperature rising back to 20˚C, see Figure 4.7.2.

Table 4.7.1: Free-thaw 24 hours temperature profile cycle

Time (hours)	Upper Limit Temperature (T_U) °C	Nominal Temperature °C	Lower Limit Temperature (T_L) °C
0	22	20	18
2	32	30	28
4	32	30	28
8	-13	-15	-17
14	-13	-15	-17
18	-13	-15	-17
24	22	20	18

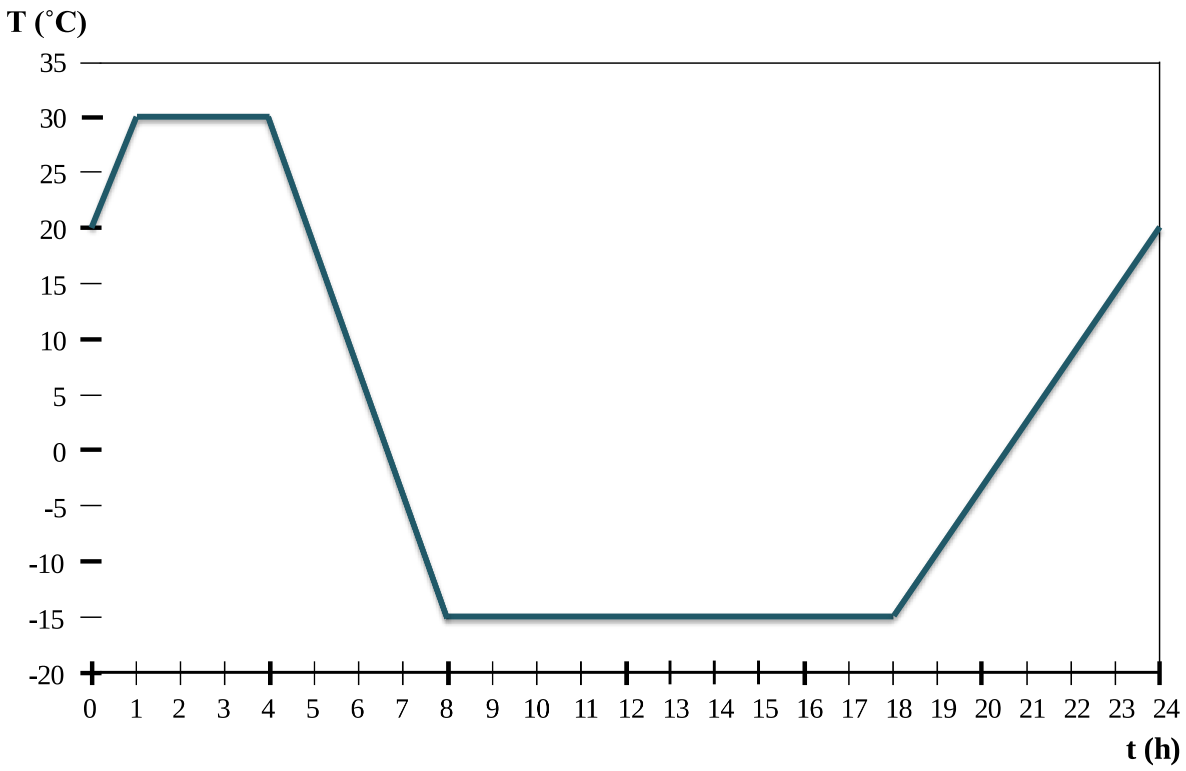

Figure 4.7.2: Temperature profile for the freeze-thaw test.

4.8. DIMENSIONAL STABILITY ASSESSMENT

Materials dimensional stability is generally influenced by factors like moisture content (water), humidity (air) and temperature fluctuations (heat), among others. For the assessment of the specimens in this study, the moisture content variations and thermal expansion were taken into account.

The shrinkage limit is defined as the moisture content at which no further volume change occurs with further reduction in moisture content. The moisture content is defined as the quantity of water contained in a material, usually expressed as a ratio between the moisture of a material (amount of water) and its dry mass. Shrinkage, weight, strength and some other materials properties are highly dependants upon the moisture content.

Thermal expansion is frequently used to characterise the physical changes in a material in response to a change in temperature. When a material is heated its particles begin moving more and thus usually maintains a greater average separation. The coefficient of thermal expansion describes how the size of an object changes with varying temperature. Several types of coefficients have been developed (volumetric, area and linear). The use of each coefficient is actually dependent on which dimensions are considered more important for the study being carried out. Linear thermal expansion is used to understand how a material behaves with temperature fluctuation.

The dimensional stability assessment tests were carried out under guidance of BS 373: 1957, BS EN 1377-2: 1990, BS ISO 11359-2: 1999 and BS EN 14617-11: 2005.

Apparatus

- Polymer decking (B001, B002, B003) $150mm \times 124mm \times 25mm$
- Typical softwood block (TSW) $150mm \times 100mm \times 48mm$
- Hardwood decking (HWD) $150mm \times 145mm \times 22mm$
- Softwood decking (SWD) $150mm \times 141mm \times 26mm$
- Digital Vernier Callipers
- Electronic scale
- Thermometer
- Oven (Controls)

Methodology

Two samples of each specimen were used for the carry out of this experiment. The samples used for the determination of the dimensional stability were saturated samples, which were submerged in water for 28 days prior to the carry out of the tests. The samples were wiped, weight and then placed in the oven in two different set of temperature (70˚C and 100˚C) over a period of 24 hours. The specimens were afterwards withdrawn from the oven and their characteristics were then assessed. For the determination of the dimensional stability assessment the following equations were used:

$Moisture\ Content\ (\omega) = \frac{w_W - w_D}{w_D} \times 100\%$ ....Equation 9

$Shrinkage\ Limit\ (SL) = 1 - \frac{L_D}{L_O} \times 100\%$ ....Equation 10

$Coefficient\ of\ Linear\ Thermal\ Expansion\ (\alpha) = \frac{\Delta_L}{L_O \times \Delta_T}$ ....Equation 11

Where:

$w_w\ =\ Weight\ of\ wet\ specimen$

$w_D\ =\ weight\ of\ oven\ dry\ specimen$

$L_D\ =\ Length\ of\ the\ oven\ dry\ specimen$

$L_O\ =\ Original\ length\ of\ the\ specimen$

$\Delta_L =\ Change\ in\ length$

$\Delta_T =\ Change\ in\ temperature$

4.9. EFFECTS of WEATHERING

Weather affects materials gradually and detrimentally. Weathering is influenced by a combination of factors, moisture (humidity, rain, dew, and snow), solar radiation (Ultra Violet (UV), light), heat, and pollutants (acid rain, ozone, etc.) which cause a degree of degradation in materials. Due to the fact that factors affecting the weathering of materials are widely present, it has to be concluded that the weathering of materials is not an exact science, rather an attempt to assess the effects of these distinct factors.

Most weathering effects on materials are caused by a combination of these factors, and it is impossible to rank the power of UV radiation, moisture, heat and the presence of pollutants in materials. The assessment in this study was gathered from observations on specimens exposed to outdoor weathering for a period of 8 months.

Apparatus

- Polymer decking (B001, B002) $150mm \times 124mm \times 25mm$
- Typical softwood block (TSW) $150mm \times 100mm \times 48mm$
- Digital Vernier Callipers
- Electronic scale
- Thermometer
- Desiccators Cabinet (Townson and Mercer Ltd.)

Methodology

Three samples of each specimen were used to carry out of this experiment. All samples were measured and their weight recorded. The samples were thereafter placed on a roof top for a period of 8 months. During the time the samples were exposed to weathering, visual monitoring was carried out. After the 8 months exposure to weathering, the samples were weighed and placed in a desiccator cabinet due to the presence of high moisture content. The samples were acclimatised for 7 days at 20˚C and after this period the temperature was raised for 40˚C due to the fact that the moisture was still present in the samples.

4.10. ENVIRONMENTAL IMPACT PROFILE

The performance evaluation and environmental profiling of the polymer decking material was studied based on the materials in this study. Wood decking was used to compare the performance of the polymer material. The profiling evaluation was carried out in consideration of the material's mode of production, materials degradation, recyclability and durability.

The analysis of some environmental concerns related to new product development is usually carried out using criteria such as, embodied carbon, embodied energy, resource depletion, use of waste landfills, users' health (regarding end product), product reuse and general perception in terms of maintenance of the material and environment.

In the current study the environmental characteristics on input energy and emissions output of the production process are considered as targets for the production of sustainable materials. At this phase it is not possible to establish the environmental profile for the new material's entire life cycle, which involves collection, analysis and extensive calculations of time consuming data. Thus, the data used as base for this assessment was referred to EPS life cycle assessment (LCA). The solo focus of the profiling was on obtaining an indication of the carbon dioxide and energy as well on carrying out an inventory of input and output emissions for the material production process.

CHAPTER 5

EXPERIMENTAL RESULTS

This chapter describes the experimental results of the tests carried out on the polymer decking specimens and the different types of wood used for the purpose of comparison. The experimental results include density tests, water absorption, and compressive strength tests among others.

5.1. DENSITY

The results presented in this section correspond to the obtained results from the determination of the densities of the specimens. The results show the density profile of the polymer decking specimens (B001, B0002 and B003), typical soft wood samples (TSW), soft wood decking samples (SWD) and hard wood decking samples (HWD), used in this experiment as comparison data.

Three samples of each specimen were initially tested daily, B001 and TSW, over a period of 20 days, and thereafter in different periods of time to observe the specimens density variation. After the initial testing, all specimens (polymer (B001, B002, and B003) and wood (TSW, SWD, and HWD)) had their density measured. At this stage the density of the specimens were measured immediately (day 0), and at 7, 14, 28, 56 and 90 days, with an exception made to SWD and HWD in which the 56th day reading was not taken due to inaccessibility to the labs over Christmas. The following figures show the profile of the densities over time of for polymer, wood (SWD and HWD). The tabulated values of these results are shown in Appendix B.

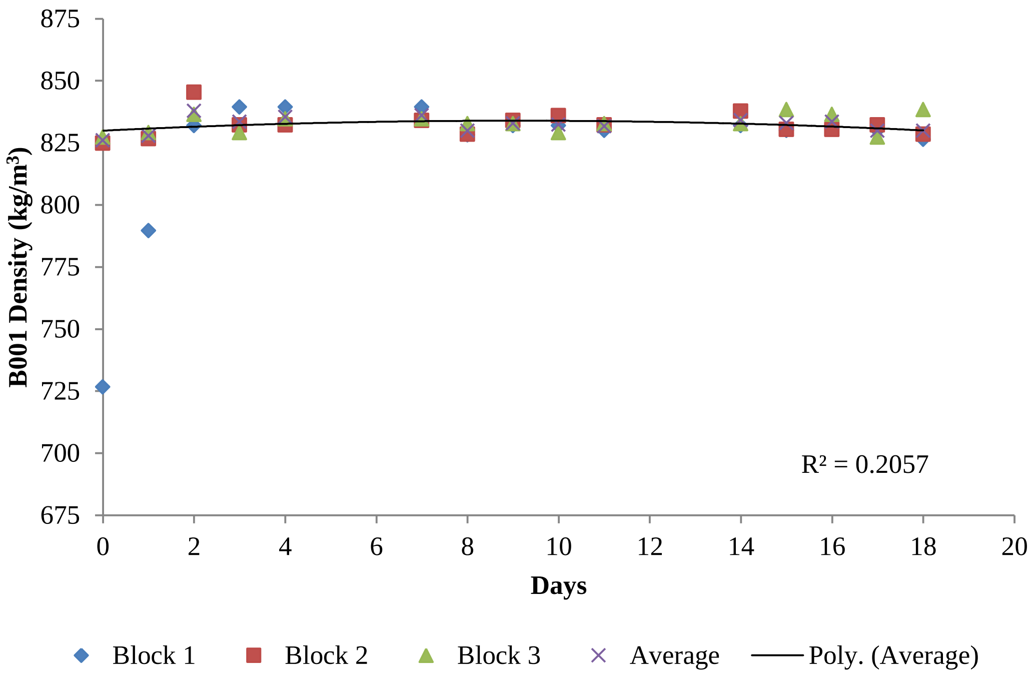

Figure 5.1.1: Polymer Decking block B001 daily density variation.

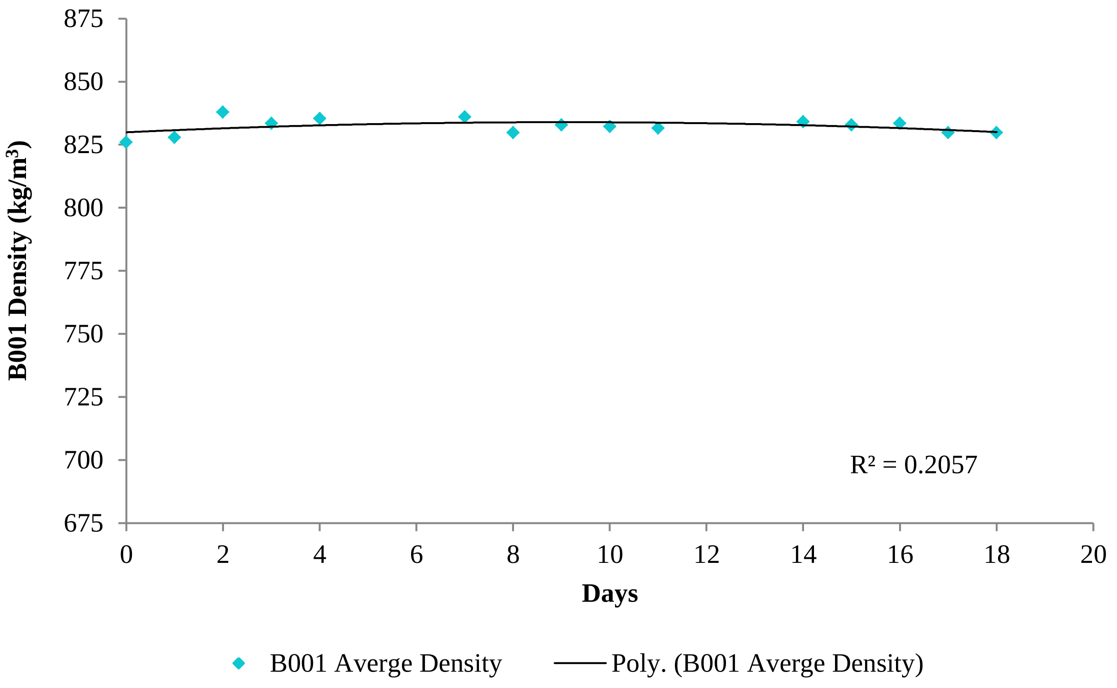

Figure 5.1.2: Polymer Decking block B001 daily average density.

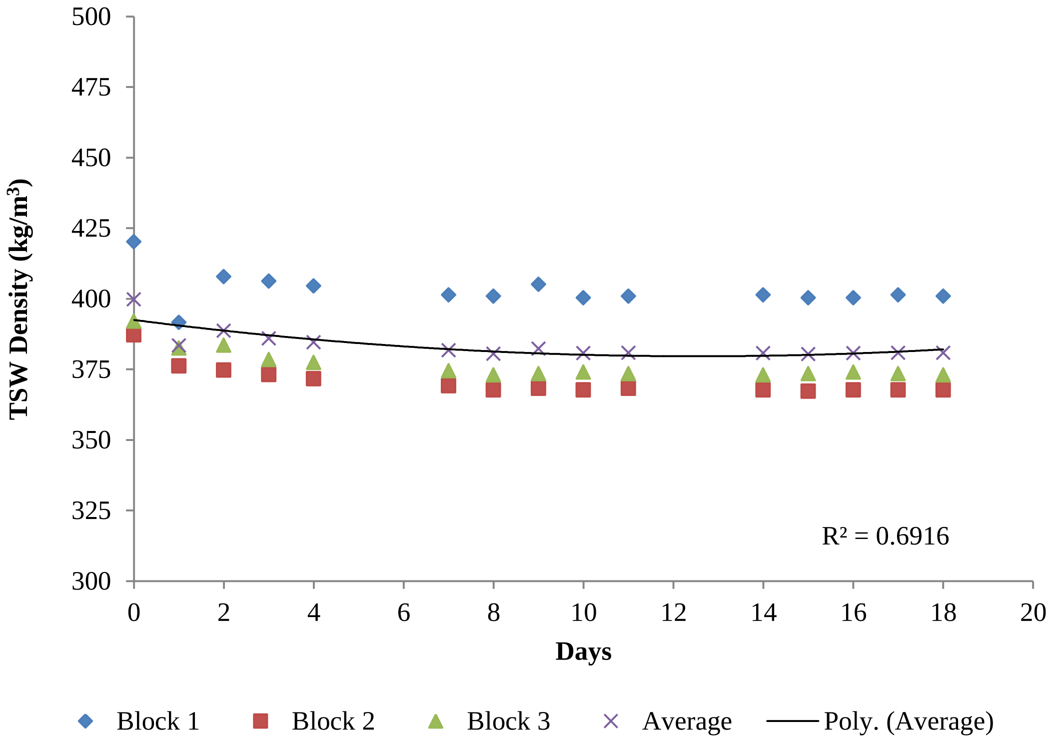

Figure 5.1.3: TSW block daily density variation.

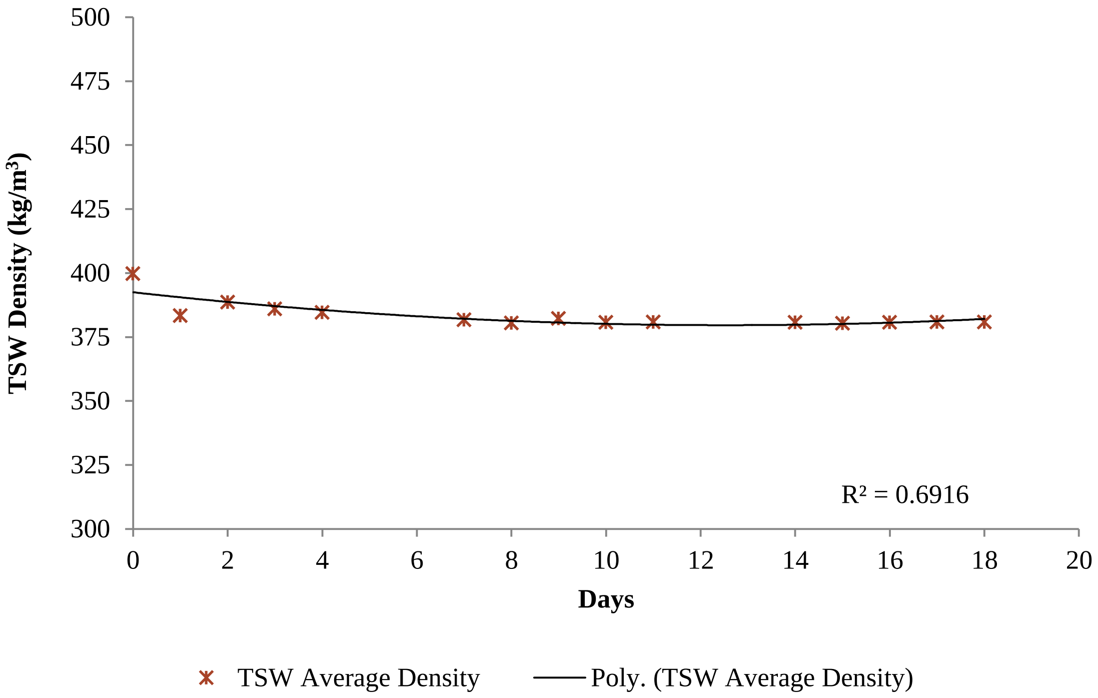

Figure 5.1.4: TSW block daily average density.

Figure 5.1.1 shows the detailed data of the first batch of polymer decking specimens (B001) received. The samples data (Block 1, Block 2 and Block 3) show similarity throughout the days, although Block 1 presents some atypical values in the initial reading (day 0) and on day 1. This figure shows that most of the density data are within a range of 825 to 840kg/m^3 with minimal variation over time. The average density daily variation data of the polymer decking specimens' block is shown in Figure 5.1.2. In this figure it can be seen that 80% of the density data is situated between 825 and 835kg/m^3. This figure gives the indication that the daily average density is of about 830kg/m^3.

Figure 5.1.3 shows the detailed data of the density variation for typical softwood (TSW) specimen, pre-existing material in the laboratory. In this figure it can be seen that the data shows a similar pattern throughout time, and the behaviour of the samples is uniform. Block 1 shows a relatively higher distribution (of about plus 33kg/m^3 for 86 per cent of the data with relation to Block 2, and of about 26kg/m^3 for 86 per cent of the data with relation to Block 3).

Block 2 and Block 3 distributions have a constant relation for 93 per cent of the data with a variation of 6 ± 1kg/m^3. The average density daily variation data for the TSW is shown in figure 5.1.4. In this figure it can be seen that 80 per cent of the density data is situated between 380 and 385kg/m^3. This figure gives the indication that the daily average density is of about 382kg/m^3.

Figures 5.1.5, 5.1.6 and 5.1.7 show the detailed data for the density variation of the three different polymer decking specimens, over a period of time of 90 days. They are Figure 5.1.5 for batch 1, B001 (90), Figure 5.1.6 for batch 2, B002 (90), and Figure 5.1.7 for batch 3, B003 (90). From these figures it can be seen that the overall data of the results obtained exhibits a linear distribution. The data of B003 (90), Figure 5.1.7, yield at a higher value at 90 days, caused by an inconsistent distribution on the 56th day. From the data provided in these figures it can be stated that the average density of the polymer decking at 90 days varies from about 850kg/m^3, for B001 (90), to about 680kg/m^3, for B002 (90). The density of B003 (90) is about 765kg/m^3, which is also the median of the ranges mentioned above.

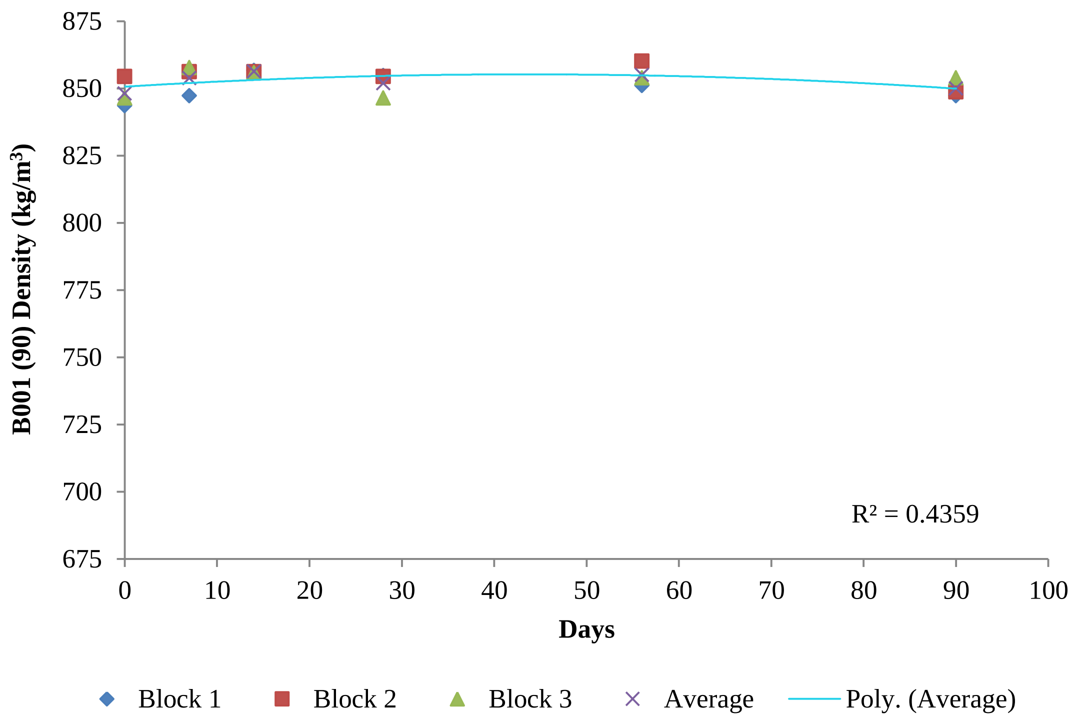

Figure 5.1.5: Polymer Decking block B001 90 days density variation.

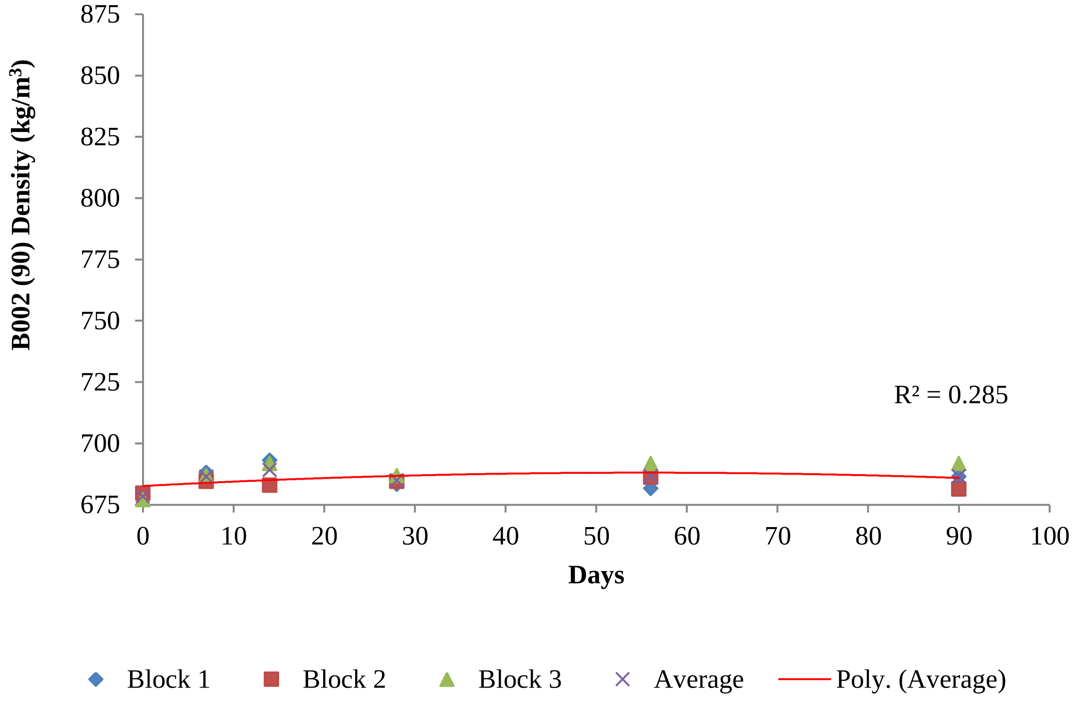

Figure 5.1.6: Polymer Decking block B002 90 days density variation.

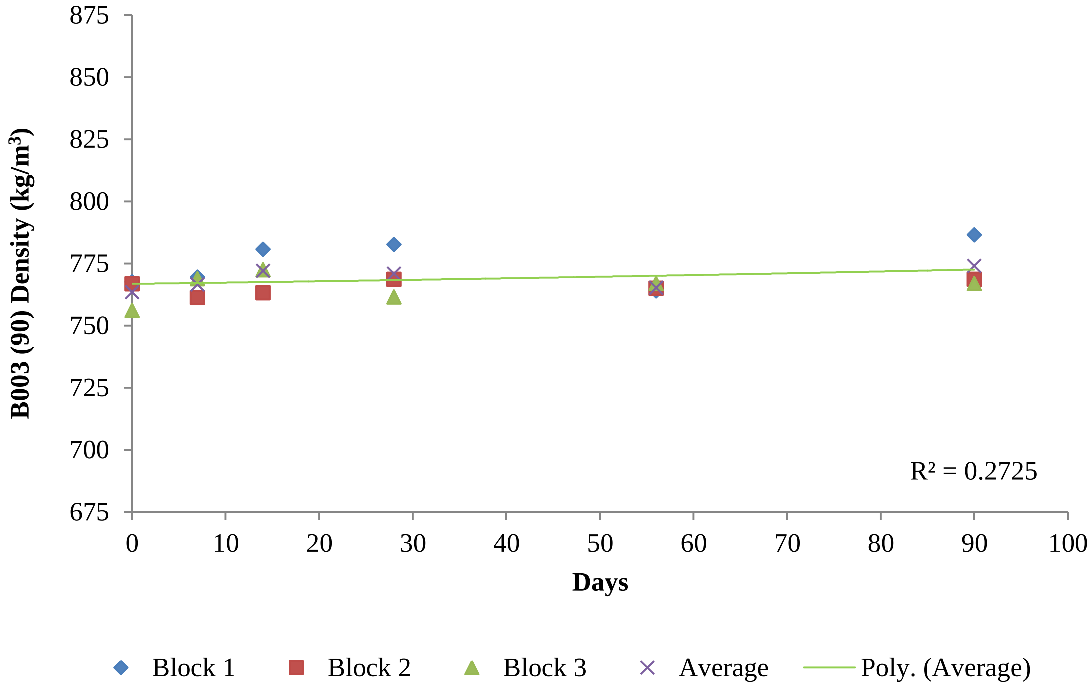

Figure 5.1.7: Polymer Decking block B003 90 days density variation.

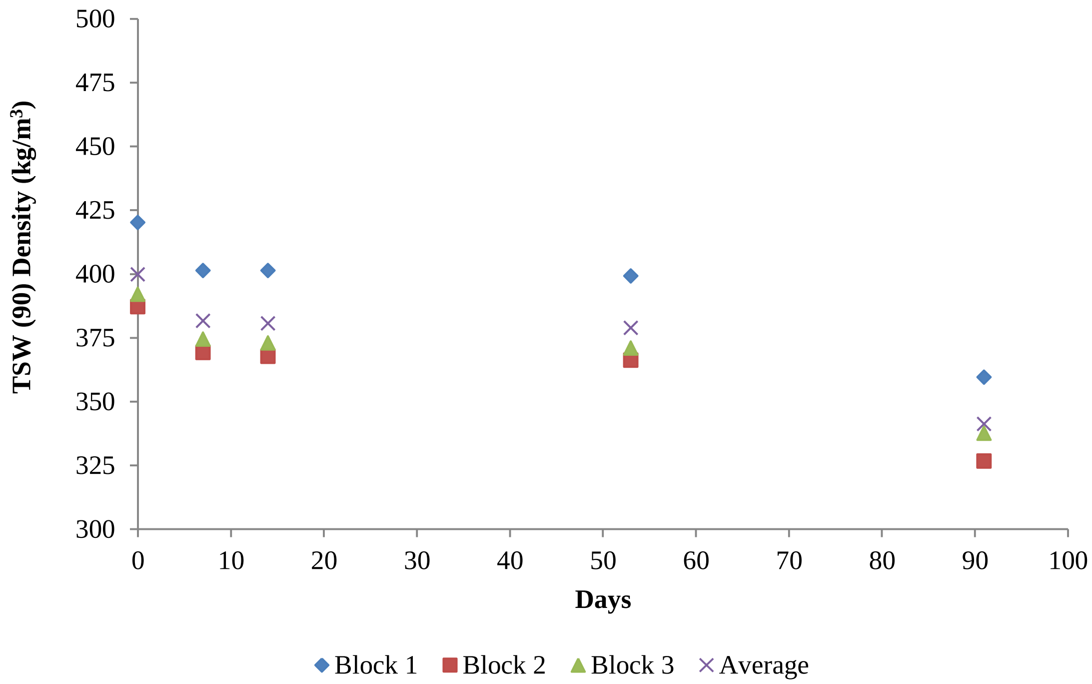

Figure 5.1.8: TSW block 90 days density variation.

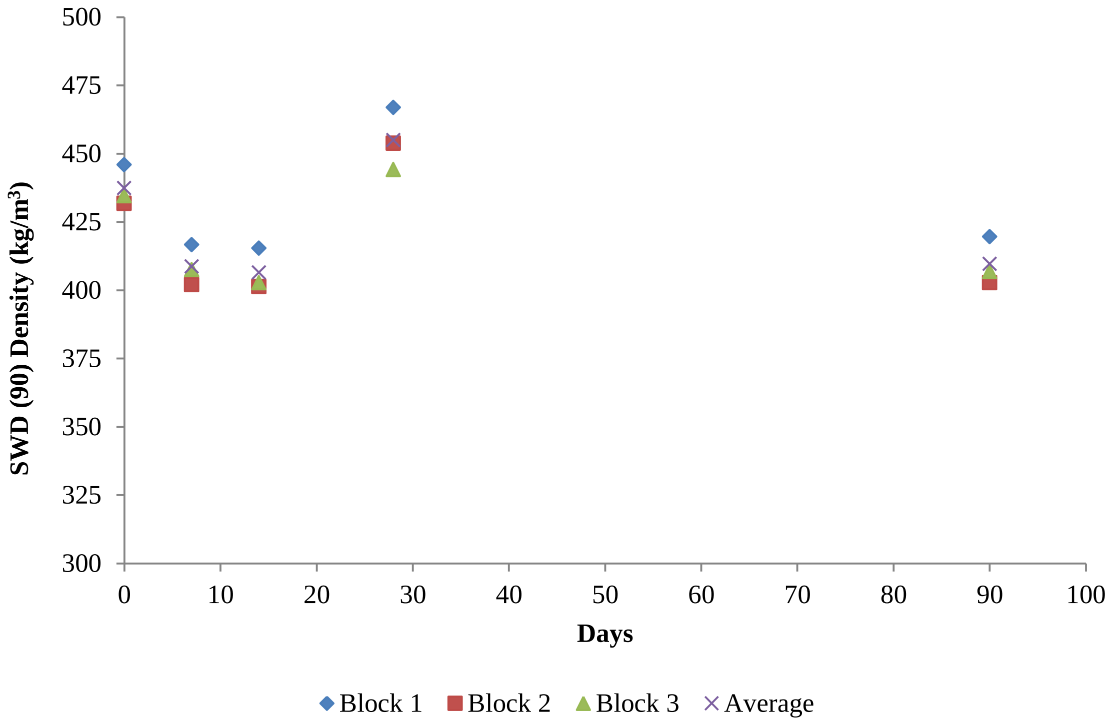

Figure 5.1.9: SWD block 90 days density variation.

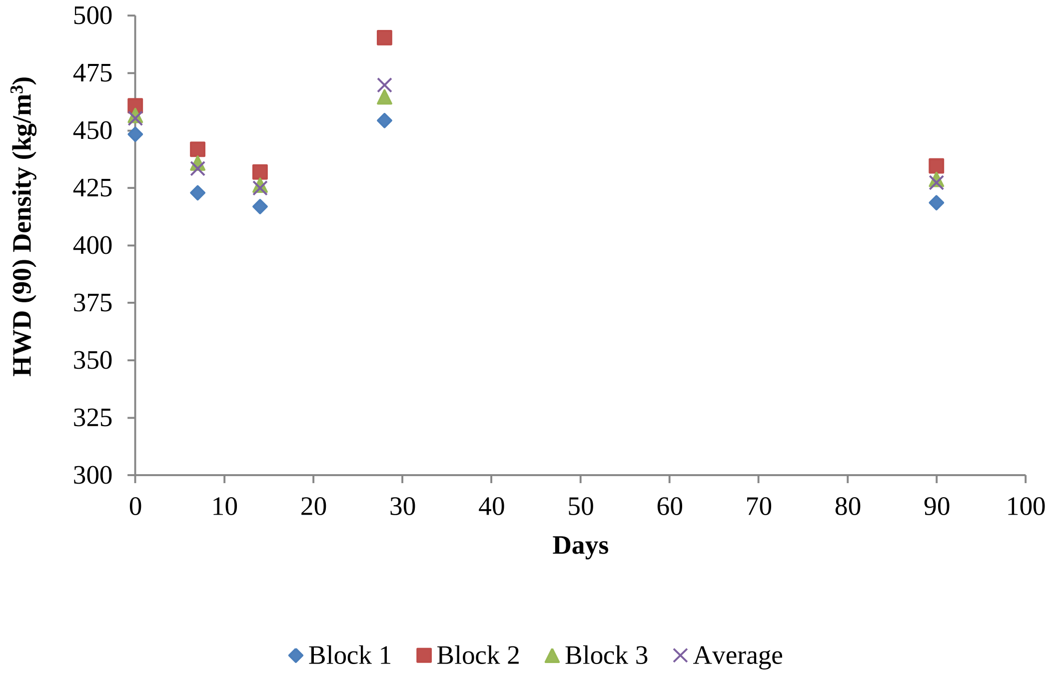

Figure 5.1.10: HWD block 90 days density variation

Figures 5.1.8, 5.1.9 and 5.1.10 show the detailed data for the density variation of the three wood specimens' used for comparison analysis in this study, over a period of time of 90 days. The wood specimens' used for the carry out of this experiment were typical soft wood, TSW (90), Figure 5.1.8, soft wood decking, SWD (90), Figure 5.1.9, and hard wood decking, HWD (90), Figure 5.1.10. The overall results show a linear distribution of the density data over the 90 days period, although the data for TSW (90), Figure 5.1.8 peaks at a lower value. From the data provided by these figures it can be seen that the average density of the wood specimens' at 90 days varies from about 380kg/m^3, for TSW (90), to about 440kg/m^3, for HWD (90). The density of SWD (90) is of about 415kg/m^3, in between the ranges mentioned above.

Results Comparison

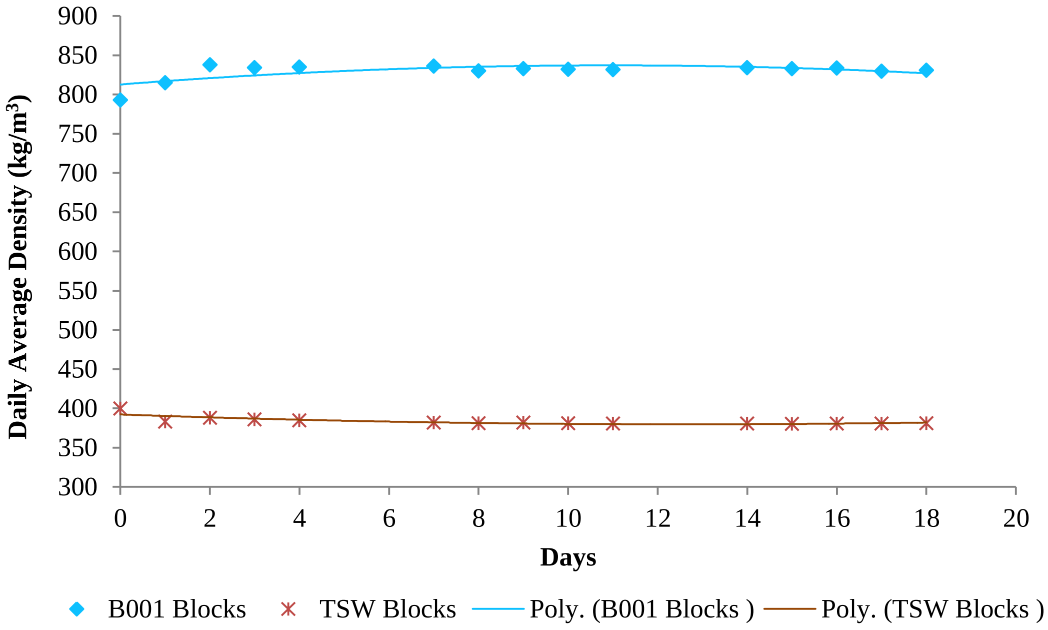

Figure 5.1.11: Daily average density comparison between B001 and TSW blocks

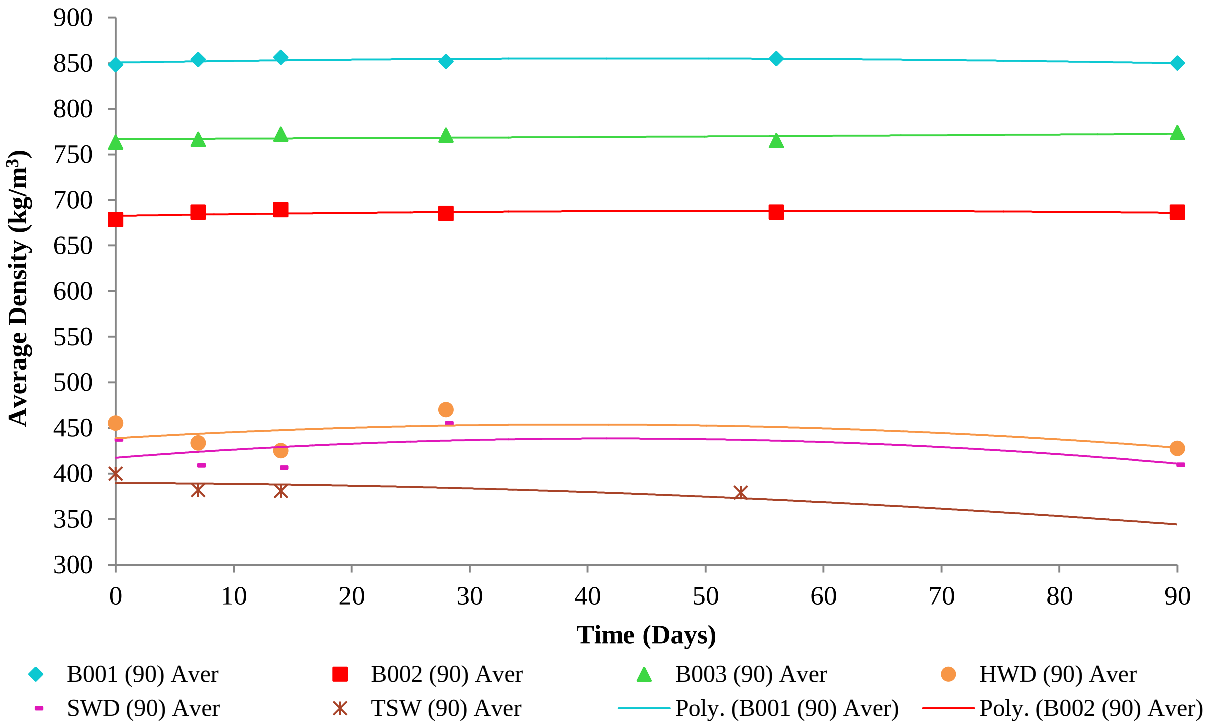

Figure 5.1.12: Specimens density comparison between Polymer Blocks (B001, B002, B003) and Wood Blocks (TSW, SWD, HWD).

Figure 5.1.11 and Figure 5.1.12 show the comparison results for polymer and wood decking specimens as well as TSW. Figure 5.1.11 shows the daily readings over 18 day's period. In this figure is possible to observe that the density of B001 is about the double of TSW. Figure 5.1.12 shows the comparison of the results over a period o 90 days. This figure shows that along time the specimens profile shows similar pattern to Figure 5.1.11, which observations corroborate one another.

Summary

From the comparison of results, it is deduced that the densities of the polymer decking specimens (B001, B002 and B003) have a higher density profile than wood specimens'. The daily average density for the polymer decking (B001) and the typical soft wood (TSW) shows that the polymer decking density is twice the value of the TSW, see figure 5.1.11. These results can be verified with the results shown in Figure 5.1.12 where the polymer decking value varies between 680 and 850kg/m^3. The same figure shows that the densities correspondent to wooden specimens (TSW, SWD and HWD) range between 380 and 440kg/m^3, which are half of the values correspondent to the polymer decking densities.

Within the polymer specimens' density, B001 shows the higher density and B002 the lower, with almost 200kg/m^3 of difference between them. With regard to wooden specimens' density, the disparity among them is not as high and the lower density value (TSW) is only about 60kg/m^3 less than the higher (HWD), as can be seen in Table 5.1.1.

Table 5.1.1: Polymer and wood specimens density

Specimen	ρ (kg/m^3)
B001	850
B002	680
B003	765
TSW	380
SWD	415
HWD	440

Table 5.1.1 shows the details of the densities of the various specimens tested. The determined density value of each specimen was given from the average density value of the three samples tested for each specimen. The density results show that the polymer decking specimens' densities are almost twice the value of the wood specimens' densities in comparison.

5.2. WATER ABSORPTION

This section presents the results obtained from the determination of the water absorption of test specimens. The results presented here show the behaviour of the test specimens when submerged in water over a period of time.

Three samples of each specimen were subjected to the water absorption test. B001 and TSW specimens were tested initially. The water absorption tests were carried out daily over a period of 20 days, and thereafter in different periods of time to observe the specimens water absorption variation.

After the initial testing, all specimens (B001, B002, B003, TSW, SWD and HWD) had their water absorption contents determined. In this phase the water content values of the specimens ware determined immediately (day 0), and at 7, 14, 28, 56 and 90 days. The figures below show the behaviour of the specimens when submerged in water over a period of time. The tabulated values of the test analyses are shown in Appendix C.

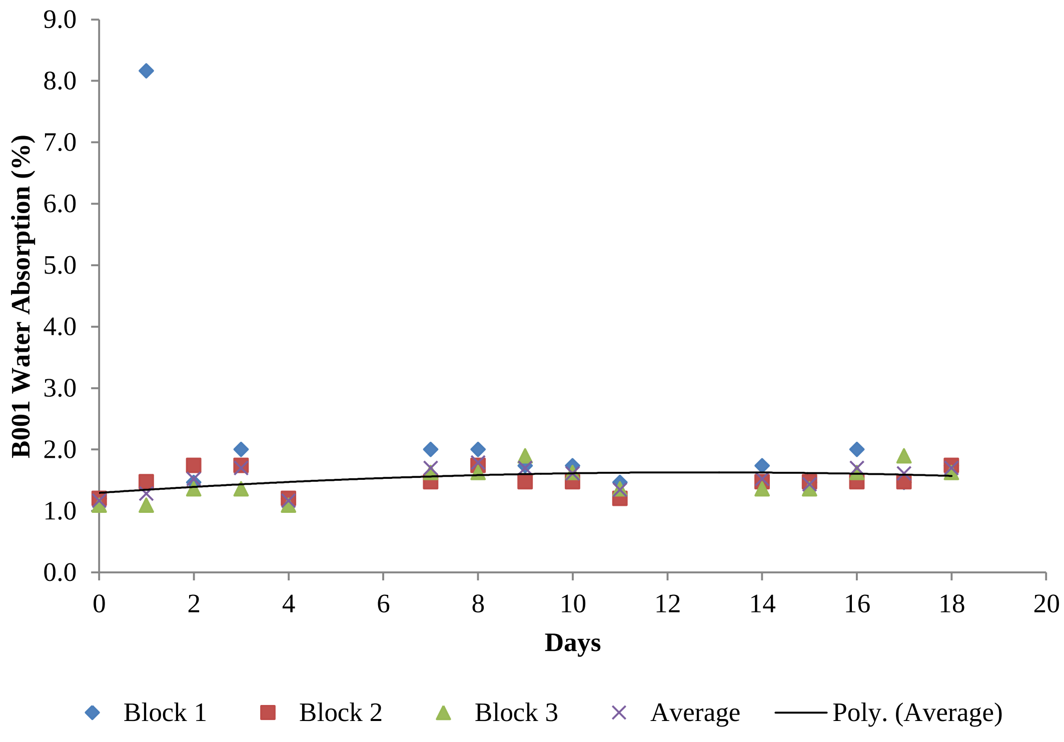

Figure 5.2.1: Polymer Decking block B001 daily water absorption variation.

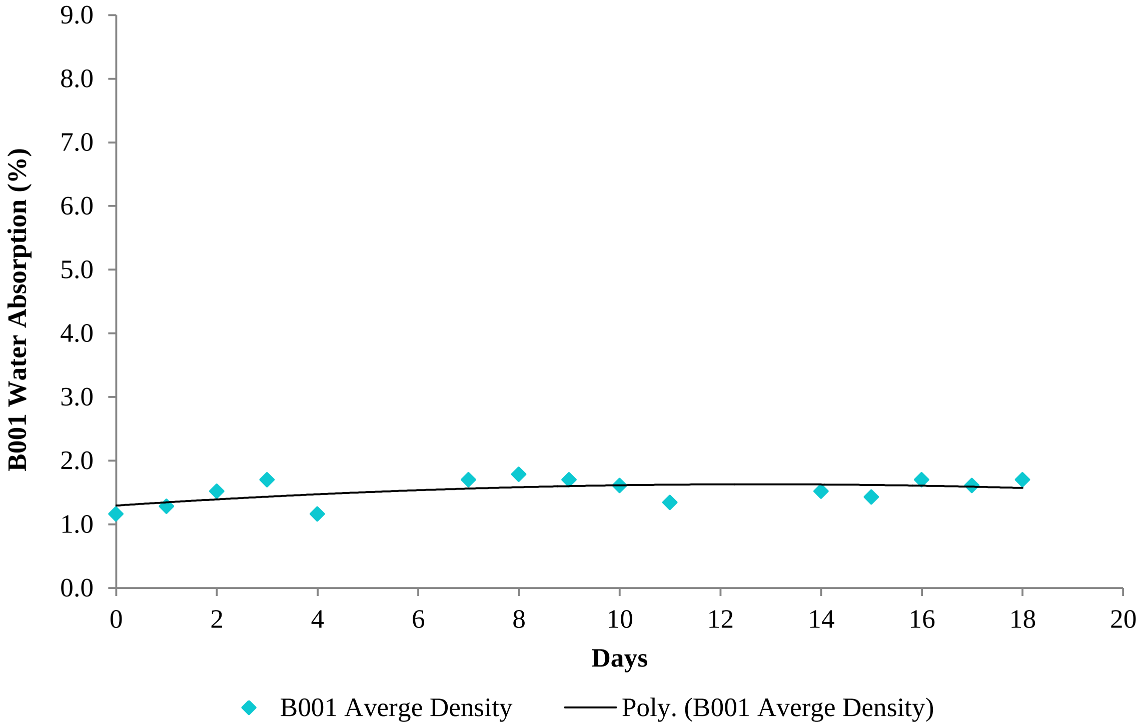

Figure 5.2.2: Polymer Decking block B001 daily average water absorption.

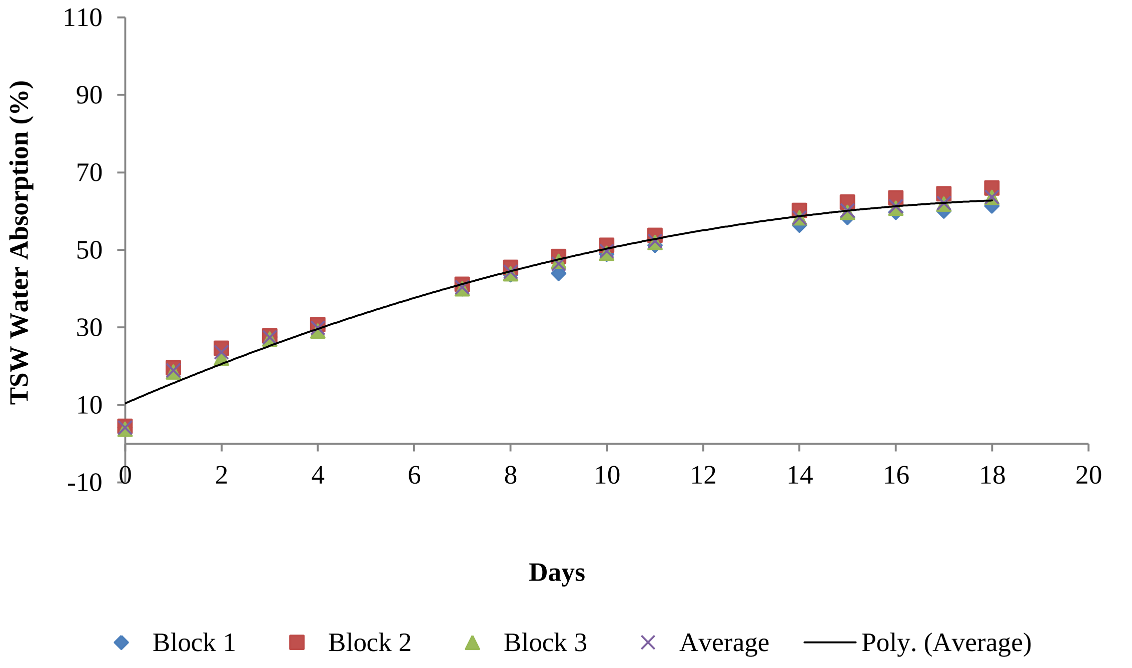

Figure 5.2.3: TSW block daily water absorption variation.

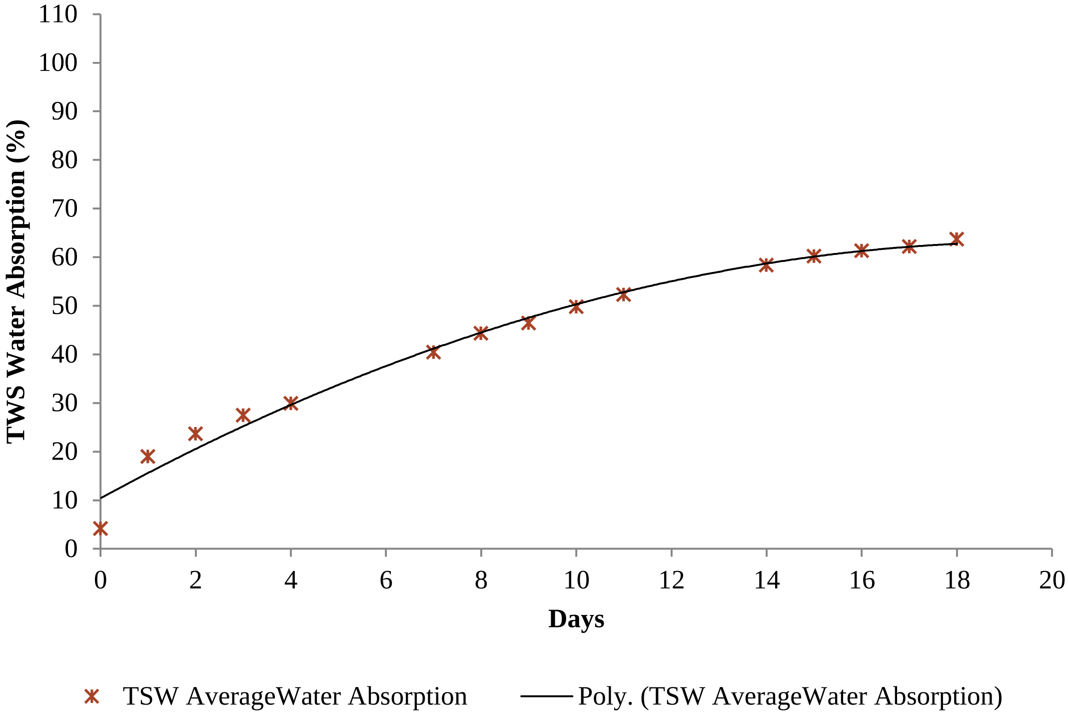

Figure 5.2.4: TSW block daily average water absorption.

Figure 5.2.1 shows the detailed data of daily variation in the rate of water absorption, for the first batch of polymer decking specimens (B001). The samples data (Block 1, Block 2 and Block 3) show a similar pattern throughout the days, although Block 1 presents an atypical value in the data on day 1. This figure shows that most of the rate of water absorption is within a range of 1 to 2 per cent, with negligible variation over time. The average variation of the rate of water absorption for this polymer decking specimen is shown in Figure 5.2.2. The figure shows that about 80 per cent of water absorption is within 1.25% and 1.75%. This indicates that the daily rate of water absorption for this specimen is of about 1.5%.

Figure 5.2.3 shows the detailed data of the daily variation in the rate of water absorption for typical soft wood (TSW) specimen. In this figure it can be seen that the data presents an increase in the rate of water absorption throughout time. This behaviour is linear and uniform for all samples (Block 1, Block 2 and Block 3 show a similar pattern along the days). The daily average rate of water absorption for the TSW is shown in figure 5.2.4. This figure shows that the increase in the rate of water absorption occurs linearly in a steady manner. This figure gives the indication that the rate of water absorption for TSW steadily increase along time. The average rate of water absorption at this stage is of about 64%.

Figures 5.2.5, 5.2.6 and 5.2.7 show the detailed data of the rate of water absorption for the three polymer decking batches, over a period of time of 90 days. Figure 5.2.5 provides the data for batch 1, B001 (90), Figure 5.1.6 provides the data for batch 2, B002 (90), and Figure 5.1.7 provides the data for batch 3, B003 (90). These figures show the similarity on the results pattern over the 90 days. The results indicate that the material absorbed water initially but after the acclimatisation of the polymer decking specimens to the water there was an expansion of the polymer macromolecules to fill the voids impeding water to penetrate the material. The results indicate also that due to the change on its macromolecules the specimens repelled the water afterwards. The negative rate of water absorption indicates that the polymer specimens swelled after being in water for 14 days. Although the values presented are negligible, it should be noted that the specimen presenting a higher value of swelling, about 4.5 per cent, corresponds to the less dense specimen, B002.

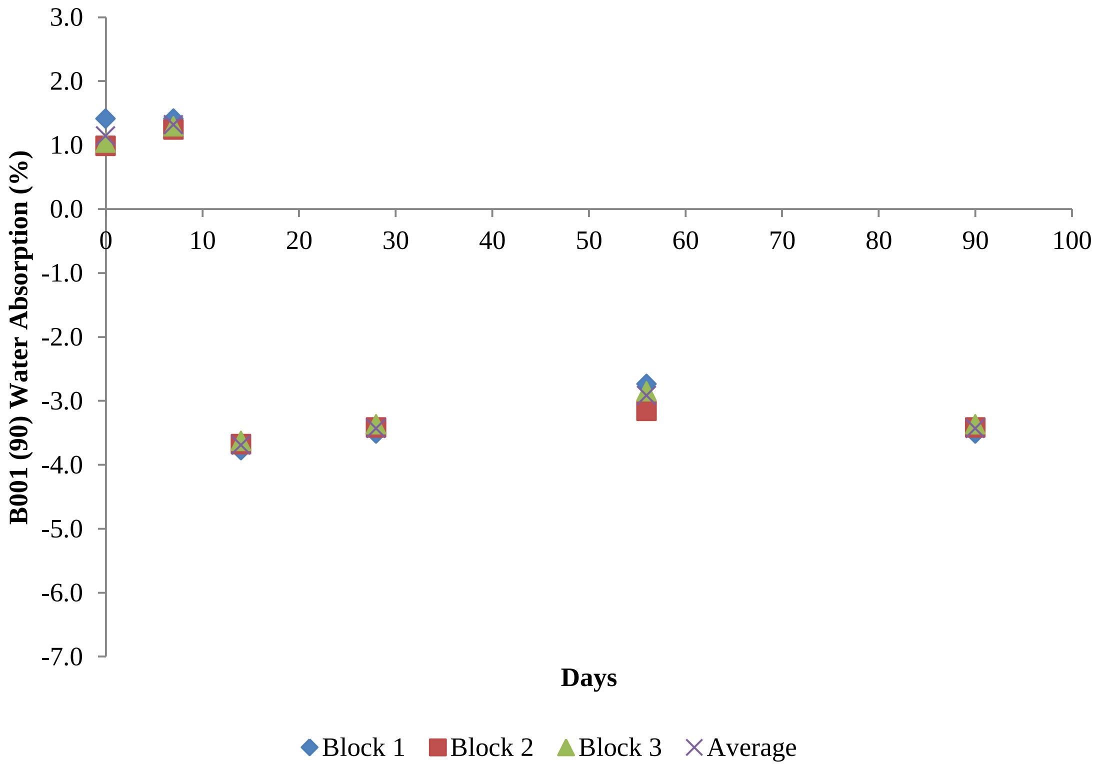

Figure 5.2.5: Polymer Decking block B001 90 days water absorption variation.

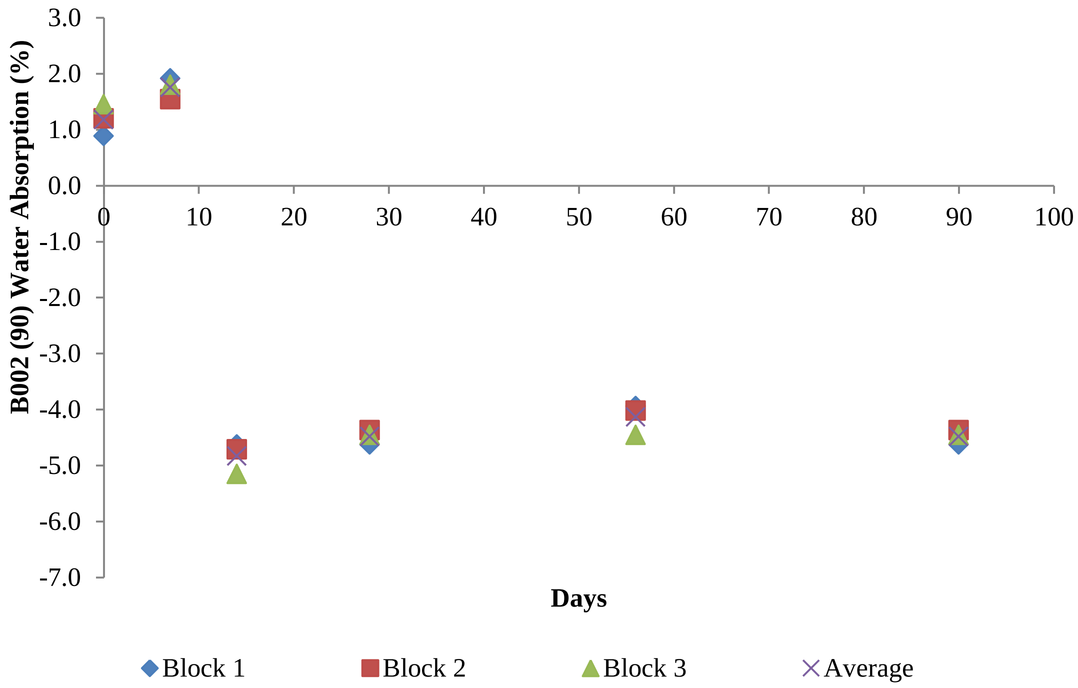

Figure 5.2.6: Polymer Decking block B002 90 days water absorption variation.

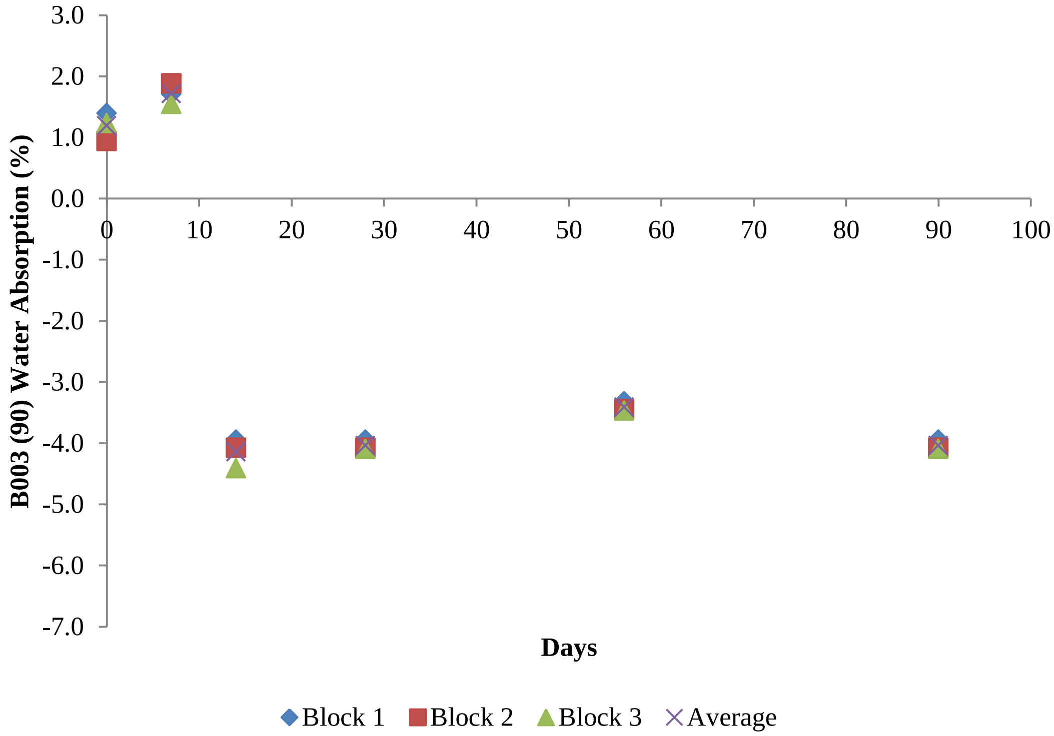

Figure 5.2.7: Polymer Decking block B003 90 days water absorption variation.

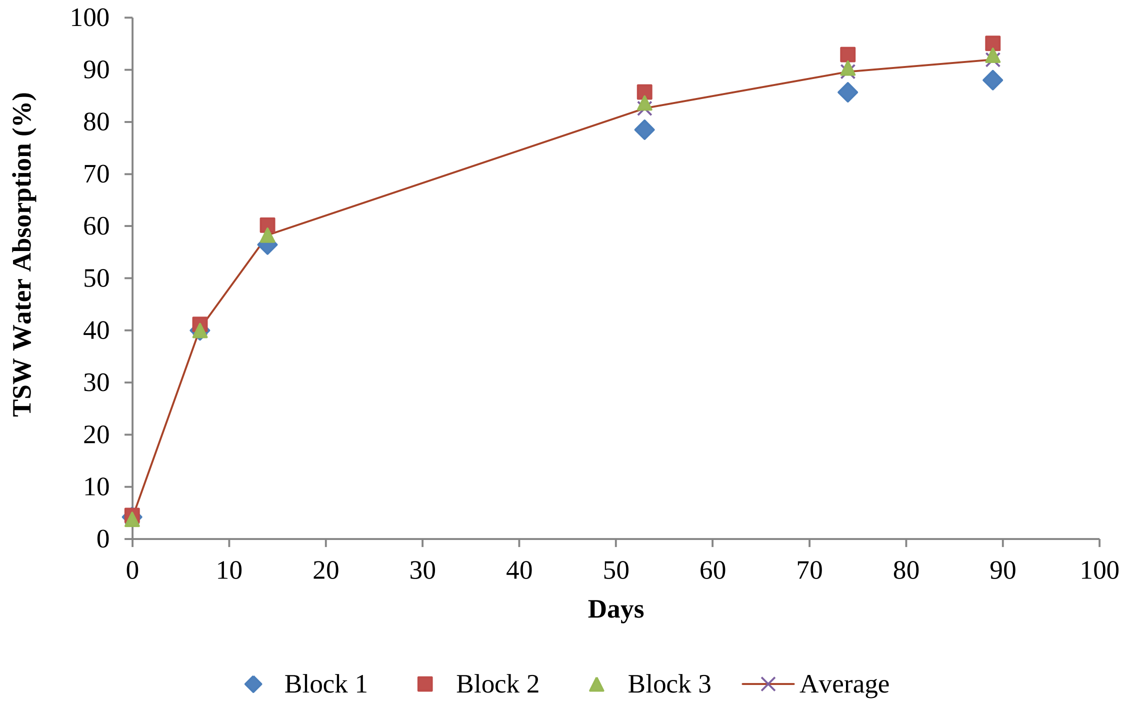

Figure 5.2.8: TSW block 90 days water absorption variation.

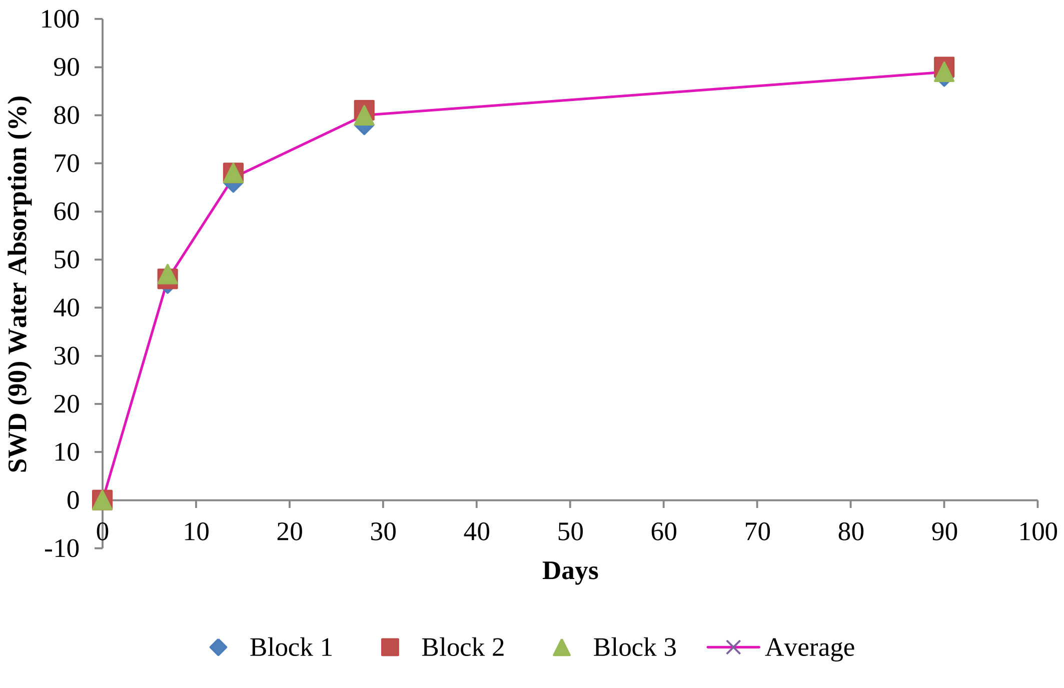

Figure 5.2.9: SWD block 90 days water absorption variation.

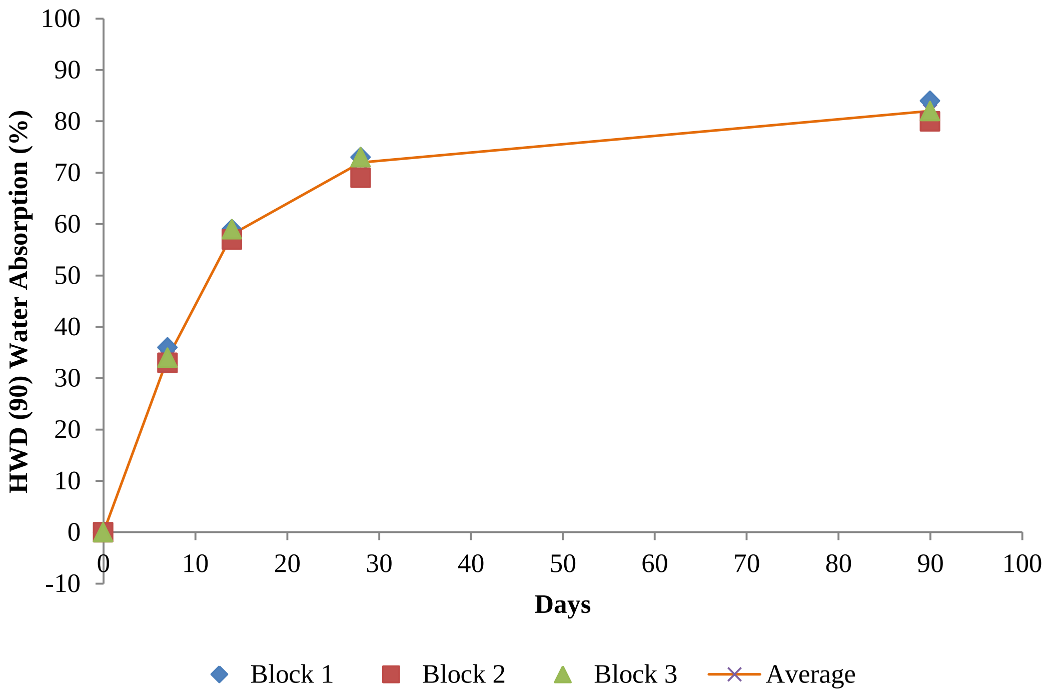

Figure 5.2.10: HWD block 90 days water absorption variation.

Figures 5.2.8, 5.2.9 and 5.2.10 show the detailed data for the rate of water absorption of the three wood specimens used for comparison analysis in this study. The wood specimens used for the carry out were typical soft wood, TSW (90), Figure 5.2.8, soft wood decking, SWD (90), Figure 5.2.9, and hard wood decking, HWD (90), Figure 5.2.10, analysed over a period of time of 90 days. On these three figures it can be seen that the specimen have a high initial rate of water absorption, absorbing about 60% of moisture in the first 14 days. Afterwards the rate of water absorption is steady and at a lower rate. The results show a linear distribution of the behaviour over the 90 days period. Overall, the figures show that the rate of water absorption occurs linearly and steadily for the three specimens (TWS, SWD, and HWD). At 90 days the rate of water absorption for wood specimens varies between 80% for HWD and 92% for TSW. The rate of water absorption for SWD is between the two mentioned above but closer to the higer value, 89%.

Results Comparison

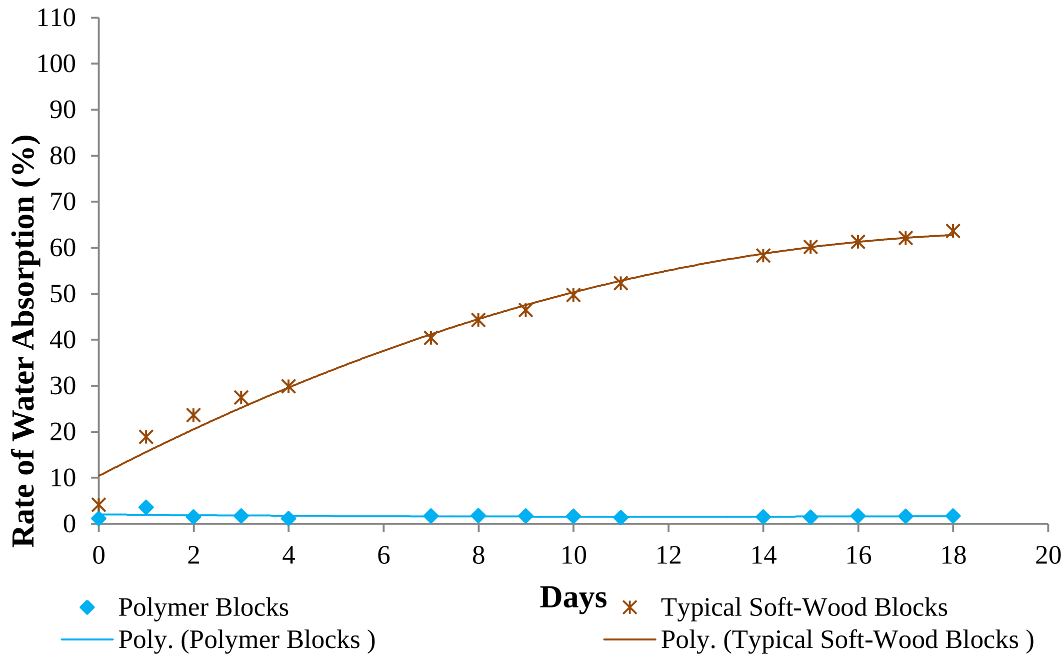

Figure 5.2.11: Daily average water absorption comparison between B001 and TSW blocks

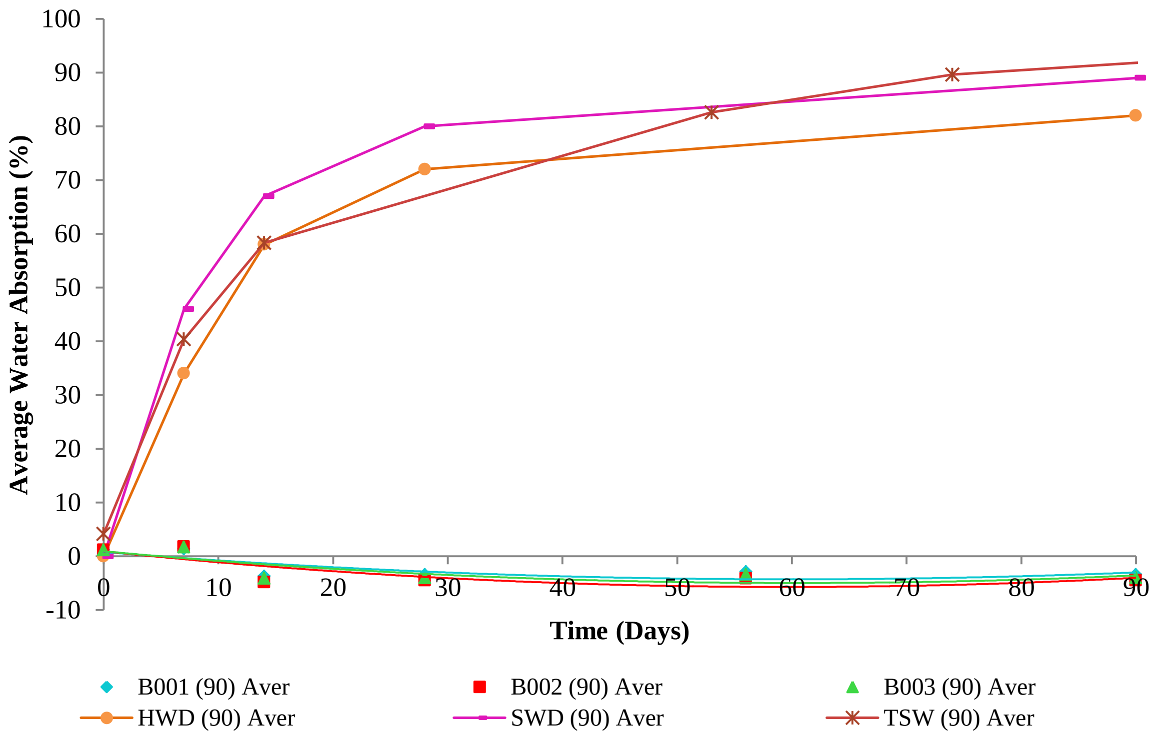

Figure 5.2.12: Specimens density comparison between Polymer Blocks (B001, B002, B003) and Wood Blocks (TSW, SWD, HWD).

Figure 5.2.11 and Figure 5.2.12 show the comparison results of the rate of water absorption for polymer and wood decking specimens as well as typical soft wood. Figure 5.2.11 shows the daily rate of water absorbed by B001 and TSW over 18 days. In this figure is possible to observe the contrast between the two specimens. Figure 5.2.12 shows the comparison of the results over a period of 90 days. This figure gives a visual interpretation of the specimens' profile. The figure shows how different the two materials are concerning water. While wood specimens at 14 days show a rate of water absorption of about 60 per cent, at the exact same period of time polymer specimens show expansion, repelling water, factor that remains constant along time.

Summary

From the results comparison it can be seen that the rate of water absorption of the polymer decking specimens (B001, B002, and B003) is negligible or inexistent. In contrast, the wooden specimens (TSW, SWD, and HWD) have a high content value of water absorption.

The same results comparison shows that the rate of water absorption of the polymer specimens is almost the same for all specimens with very little variation among them as can be seen in Table 5.2.1. This highly differs from the results for the wooden specimens, which show initially and along time a high of the rate of water absorption.

Within the polymer specimens', B001 shows the lower rate of water absorption and B002 the higher, but the disparity between them is almost absent. On the other hand, the rate of water absorption of the wooden specimens' is very high over the same period of time. HWD shows the lower rate of water absorption, about 82% and TSW the higher rate, about 10% more, as can be seen in Table 5.2.1.

Table 5.2.1: Polymer and wooden specimens' rate of water absorption

	Specimen	W_w (%) at day 90	W_w (%) mean values
Polymer	B001	-3.43	-1.83
	B002	-4.63	-2.50
	B003	-4.04	-2.12
Wood	TSW	92	61
	SWD	89	56
	HWD	82	49

Table 5.2.1 shows the details of the rate of water absorption. These values were determined from the average rate of water absorption of the three samples tested for each specimen.

5.3. COMPRESSIVE STRENGTH

The results presented in this section show the analysis of the data on the comprehensive strength tests. The assessment of the strength of the specimens allows the interpretation of the resistance of specimens to elastic (recoverable) deformation when load is applied.

The compressive strength of the specimens was determined by local control method. Initially three samples of batch one were used for the tests with 0.167kN/s and 0.333kN/s load rate applied on the different orientation of the samples (Axial, Vertical and Transversal). However, the overall results presented were given from the average of four samples for each test of the specimens, for each load rate and on each direction. TSW specimens were not used to carry out this experiment.

This experiment was carried out with cube samples. The load was applied through a hydraulic actuator, which measured the response of the samples via load cell by means of a load-control method. The area of the cubes where the load was applied was calculated for each sample.

Tables 5.3.1 to 5.3.6 show the calculated values of the strength, strain and modulus elasticity of each specimen, according to the different orientation load rates. Figures 5.3.1 to 5.3.8, showed in this section, give a visual interpretation of the various specimens' elastic deformation. The raw data used for the calculations of these results are shown in Appendix D.

Table 5.3.1: Polymer decking B001 compressive strength results (Trial tests)

B001(a)						
	σ (N/mm^2)		ε		E (N/mm^2)	
Load rate	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**
Axial	53.51	46.48	0.042	0.037	1284.94	1266.23
Transversal	37.21	35.44	0.033	0.029	1124.54	1222.55
Vertical	41.26	54.09	0.033	0.038	1265.58	1423.19

Table 5.3.2: Polymer decking B001 compressive strength results

B001(b)						
	σ (N/mm^2)		ε		E (N/mm^2)	
Load rate	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**
Axial	45.21	47.90	0.034	0.033	1329.63	1434.44
Transversal	27.97	34.17	0.026	0.029	1057.33	1168.74
Vertical	49.84	46.12	0.024	0.029	2065.84	1573.60

Table 5.3.3: Polymer decking B002 compressive strength results

B002						
	σ (N/mm^2)		ε		E (N/mm^2)	
Load rate	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**
Axial	37.29	41.96	0.037	0.034	1002.01	1232.25
Transversal	27.01	18.62	0.028	0.022	975.09	854.29
Vertical	41.07	21.07	0.030	0.027	1365.19	779.91

Table 5.3.4: Polymer decking B003 compressive strength results

B003						
	σ (N/mm^2)		ε		E (N/mm^2)	
Load rate	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**
Axial	29.46	31.93	0.037	0.032	785.73	992.53
Transversal	15.78	20.07	0.024	0.027	656.60	736.57
Vertical	39.37	42.89	0.028	0.037	1400.97	1167.92

Table 5.3.5: Softwood decking compressive strength analysed results

SWD						
	σ (N/mm^2)		ε		E (N/mm^2)	
Load rate	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**
Axial	47.10	49.20	0.022	0.020	2162.29	2414.43
Transversal	4.17	3.45	0.018	0.020	230.68	174.90
Vertical	7.04	5.91	0.019	0.019	379.83	312.09

Table 5.3.6: Hardwood decking compressive strength analysed results

HWD						
	σ (N/mm^2)		ε		E (N/mm^2)	
Load rate	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**	**0.167kN/s**	**0.333kN/s**
Axial	47.94	52.11	0.021	0.022	2322.44	2415.22
Transversal	5.52	6.35	0.010	0.011	573.76	562.44
Vertical	11.33	10.38	0.022	0.018	504.92	562.25

The tables showed in this section, Table 5.3.1 to Table 5.3.6, provide the explanatory data of the load bearing capacity of the polymer and wood decking specimens to withstand load, compressive strength (σ). The data shown in these tables also provide a narrative of the deformation of the materials in terms of its particle relative displacement, strain (ε).

The polymer specimens' results shown in Tables 5.3.1, 5.3.2, 5.3.3 and 5.3.4 indicate that generally polymer decking specimens have high compressive strength values (axial, vertical and transversal axes) when compared to wood decking specimens, Tables 5.3.5 and 5.3.6. Axially, the strength value for B001, SWD and HWD ranges between 45 to 54N/mm^2 at 0.167kN/s, and between 46 to 52N/mm^2 at 0.333kN/s of load applied. Nevertheless, the strength value of the wood decking specimens (SWD and HWD) for vertical and transversal axes are highly low when compared to the polymer specimen (B001).

The strength for the other polymer specimens (B002 and B003) show similar pattern to B001, although with lower values. B003 has the weakest strength value of the polymer specimens, see Figure 5.3.1 and Figure 5.3.2. Similarly, the strain values of the polymer specimens are higher than the strain values for the wood specimens. This higher variation of the strain value represents a higher deformation of the specimens, which corresponds to higher damage of the material at its compressive failure load. The depiction in strain variation can be seen in Figure 5.3.3 and Figure 5.3.4.

The strength/strain relationship allowed the calculation of the Modulus Elasticity (E) for each specimen. Figures 5.3.5 and 5.3.6 provide the illustration of the elastic modulus (E) for each specimen. This figures show that both wood specimens (SWD and HWD) have a high stiffness axially (between 2100 and 2400N/mm^2) but are really weak vertically and transversally (ranging from 170 to 570N/mm^2). The same figures show that the modulus elasticity of the polymer specimens, despite having significant lower values, is distributed over the three axes.

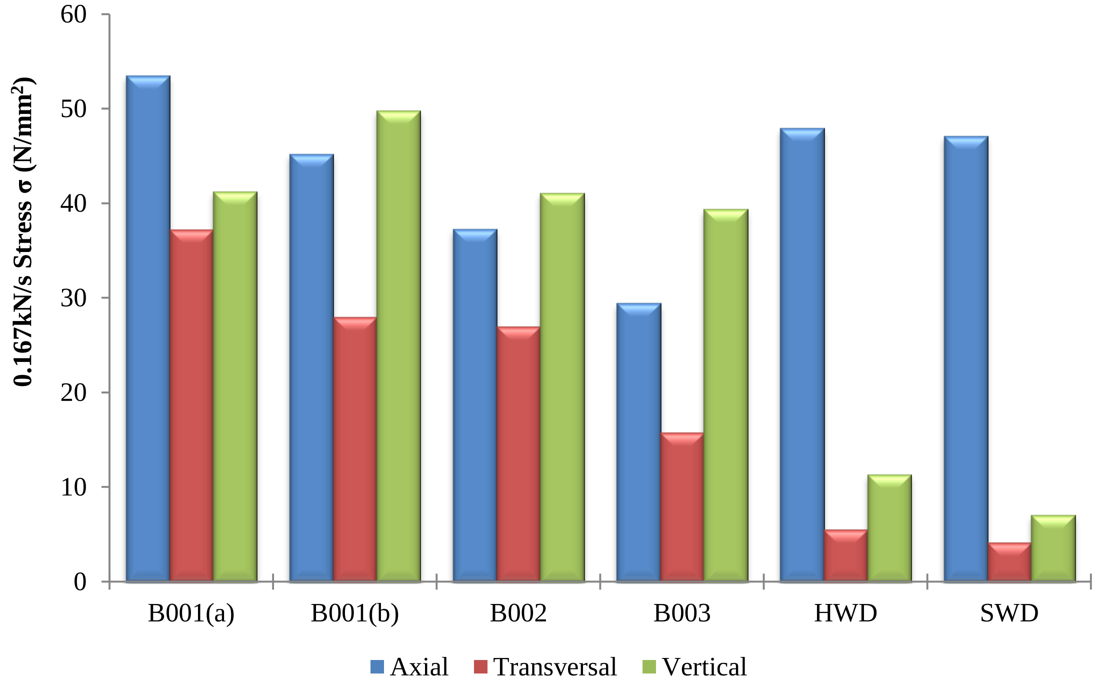

Figure 5.3.1: Specimens stress values comparison for a load rate of 0.167kN/s.

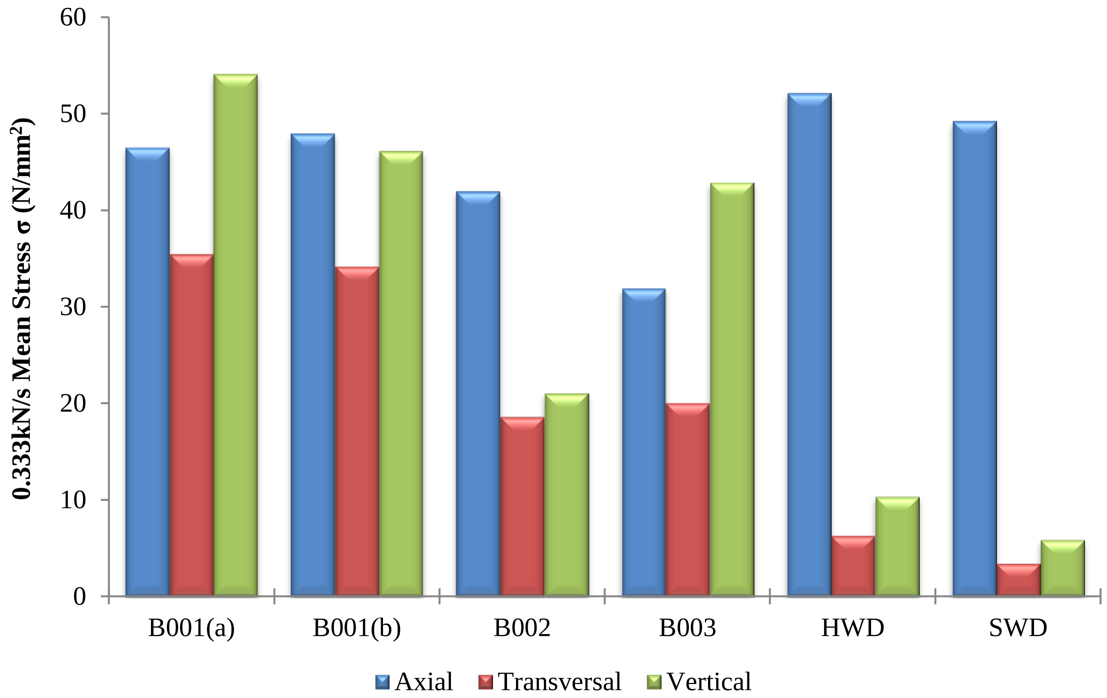

Figure 5.3.2: Specimens stress values comparison for a load rate of 0.333kN/s.

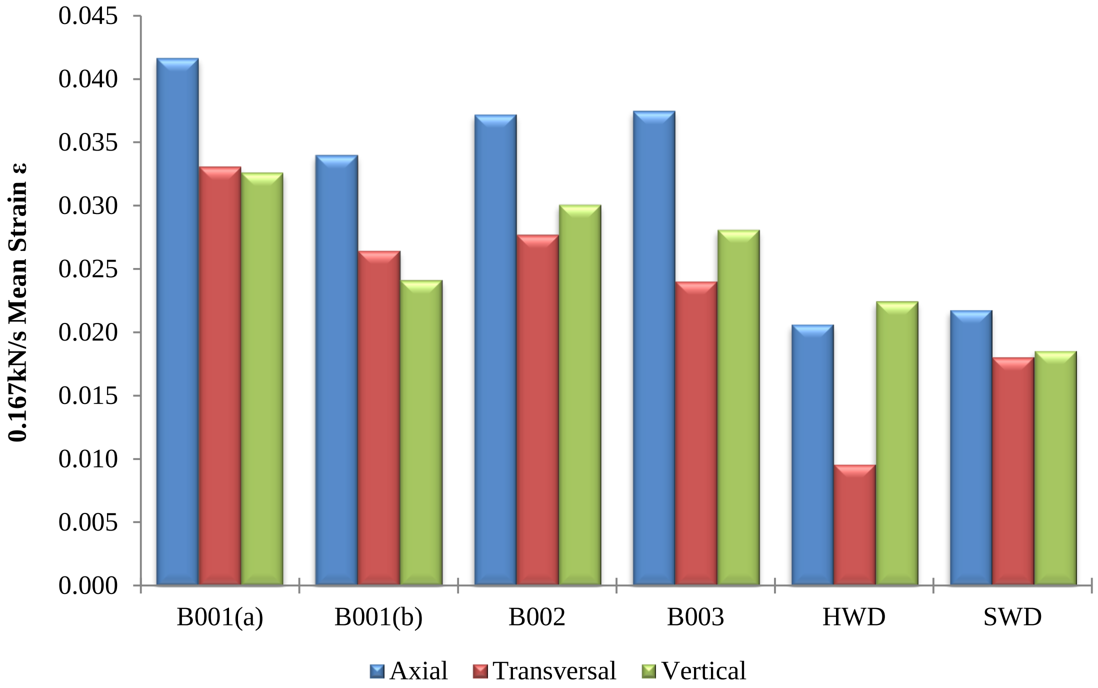

Figure 5.3.3: Specimens strain values comparison for a load rate of 0.167kN/s.

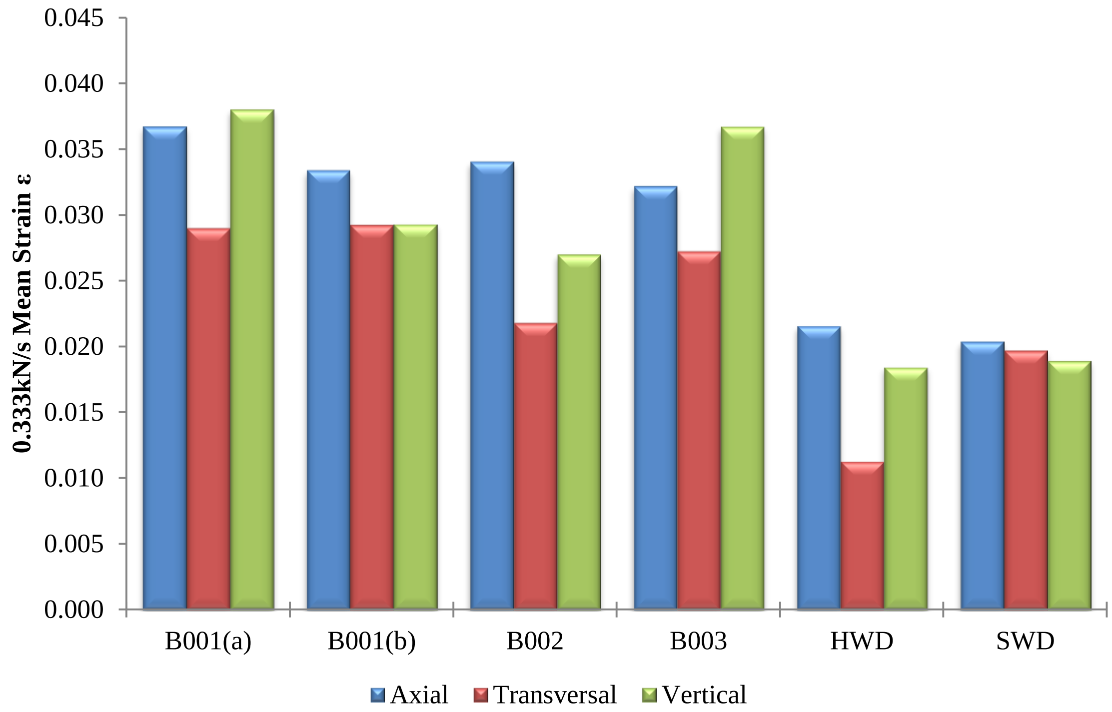

Figure 5.3.4: Specimens strain values comparison for a load rate of 0.333kN/s.

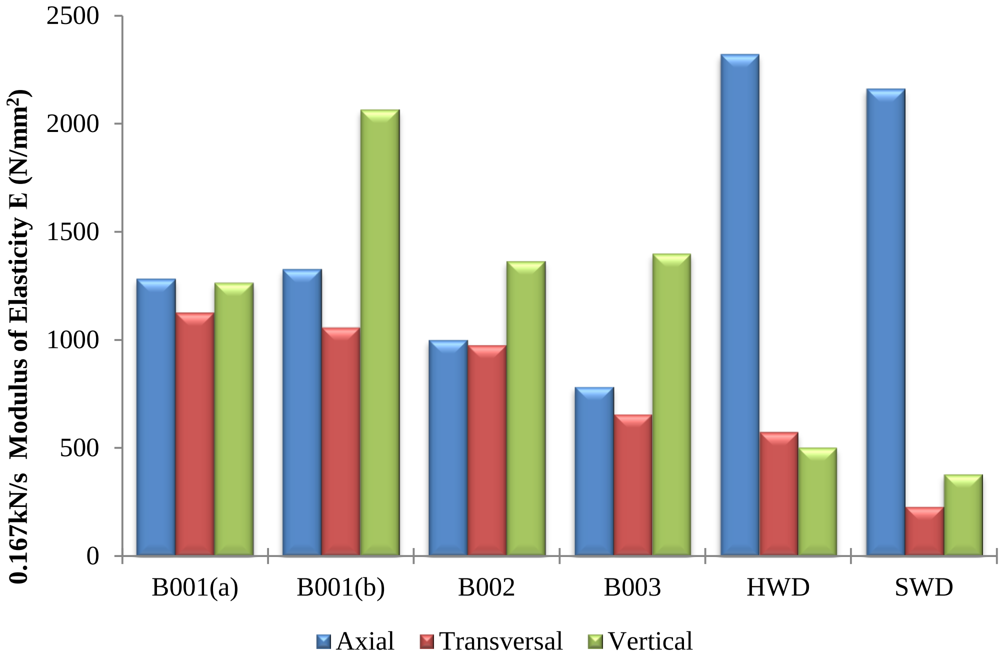

Figure 5.3.5: Comparison of the specimens' modulus of elasticity values, in compression for a load rate of 0.167kN/s.

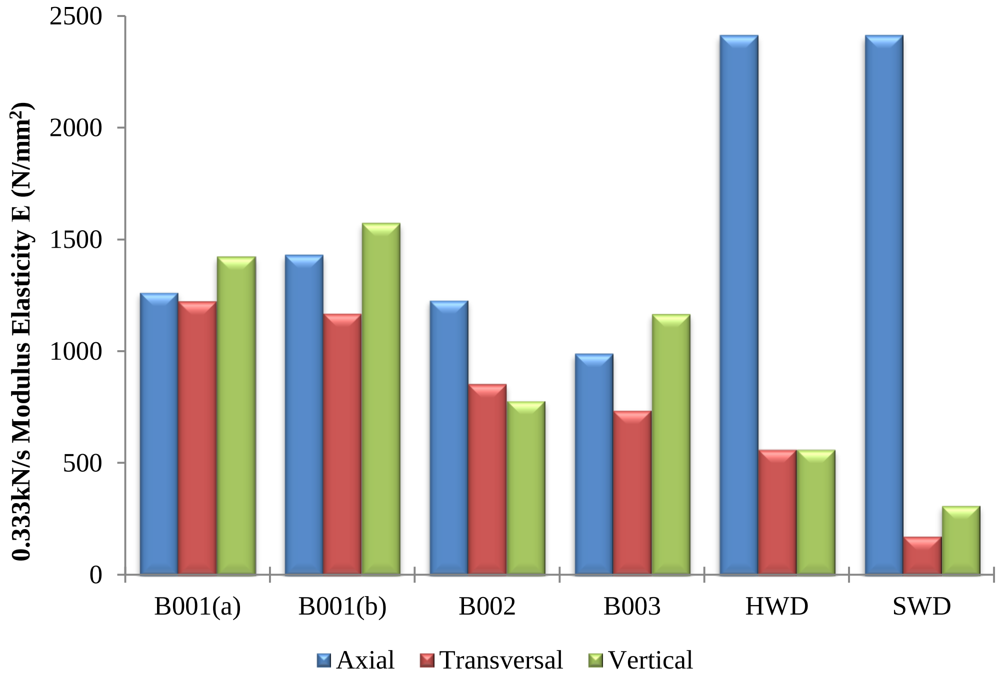

Figure 5.3.6: Comparison of the specimens' modulus of elasticity values, in compression, for a load rate of 0.333kN/s.

Results Comparison

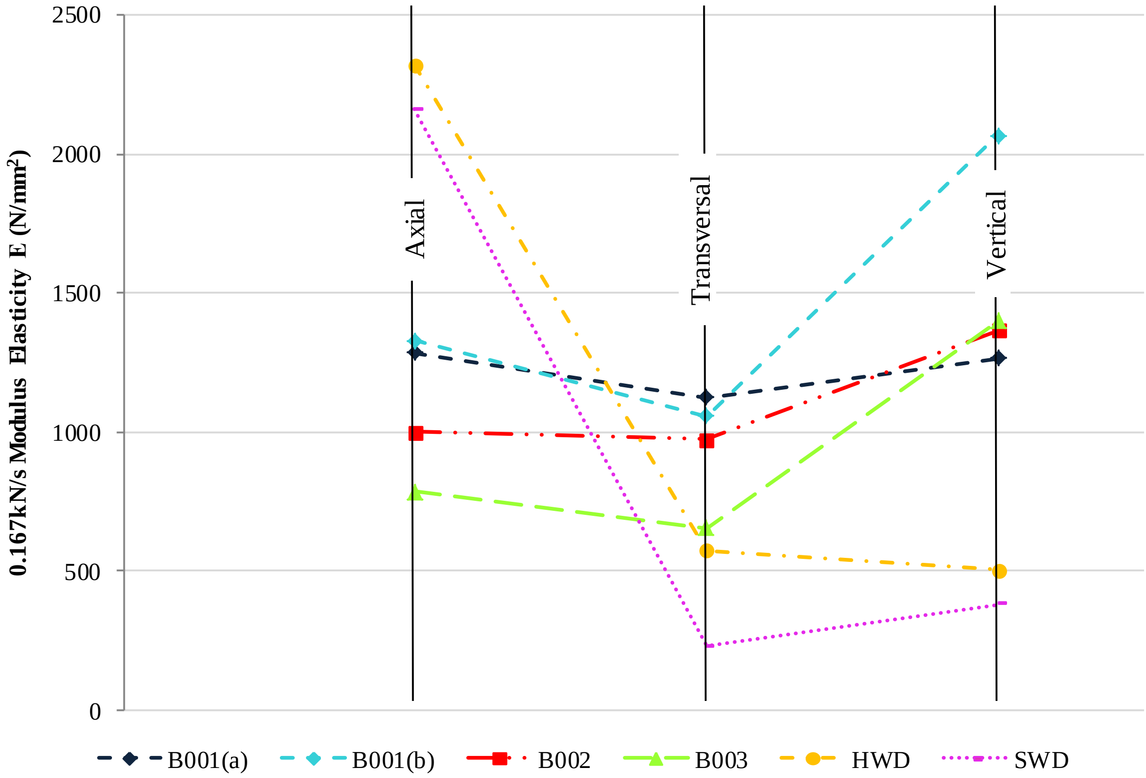

Figure 5.3.7: Specimens 0.167kN/s compressive modulus of elasticity.

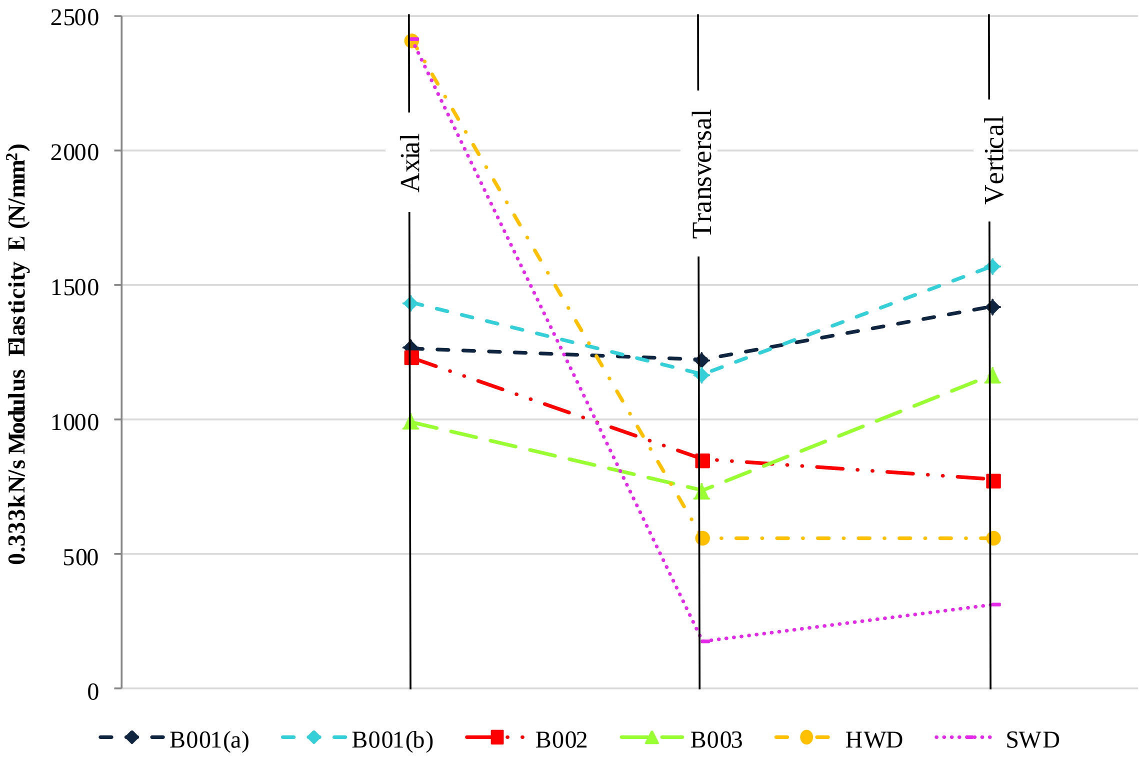

Figure 5.3.8: Specimens 0.333kN/s compressive modulus of elasticity.

Figure 5.3.7 and Figure 5.3.8 depict the profile of the modulus of elasticity (E) of each specimen. In both figures it can be seen that the HWD and SWD have the higher elasticity axially and low elasticity vertical and transversally. The same figures show that polymer decking specimens have a variable and interchangeable elasticity on their axes with most of the elasticity values fluctuating between 1000 and 1500N/mm^2.

Summary

From the results comparison it can be seen that the rate of deformation of the polymer decking specimens show similar results on the different orientations and variable elasticity on its axes. The results show that from the polymer decking specimens B001 have the most homogeneous elasticity.

The values obtained for B002 and B003 show similarities on the results presented, although this similarity is present at different axes. In comparison, the result for wood specimens shows that SWD and HWD have a high axial elastic modulus on the plane parallel to the grains of the wood but really low elastic modulus on the other orientations. The overall results and variations are shown in Table 5.3.7.

Table 5.3.7: Specimens compressive Modulus of Elasticity

	E (N/mm^2)		
Specimen	**Axial**	**Vertical**	**Transversal**
B001 (a)	1266 – 1283	1423 – 1266	1125 – 1223
B001 (b)	1330 – 1434	2066 – 1574	1057 – 1169
B002	1002 – 1232	780 – 1365	854 – 975
B003	786 – 993	1168 – 1401	657 – 737
SWD	2162 – 2414	312 – 380	175 – 380
HWD	2322 – 2415	505 – 562	562 – 574

Table 5.3.7 shows the specimens variations in the modulus of elasticity, when subjected to compressive load rate.

5.4. FLEXURAL STRENGTH

The results shown in this section are correspondent to modulus of rupture or bending strength of the specimens. The bending strength analysis is an important engineering parameter to identify the materials ability to resist to deformation, under load. The flexural strength test represents the highest stress experienced within the material at its moment of rupture.

In order to carry out this test, three small planks of polymer decking sample (B001) and softwood decking sample (SWD) were used. The load was applied transversally on the planks using the three points flexural test technique. The load was applied mechanically and the deflection recorded.

Figures 5.4.1 and 5.4.3 show the flexural trends of the specimens used for this experiment and also provide a visual interpretation of the materials resistance to deformation. The data used for the calculations of these results are shown in Appendix E.

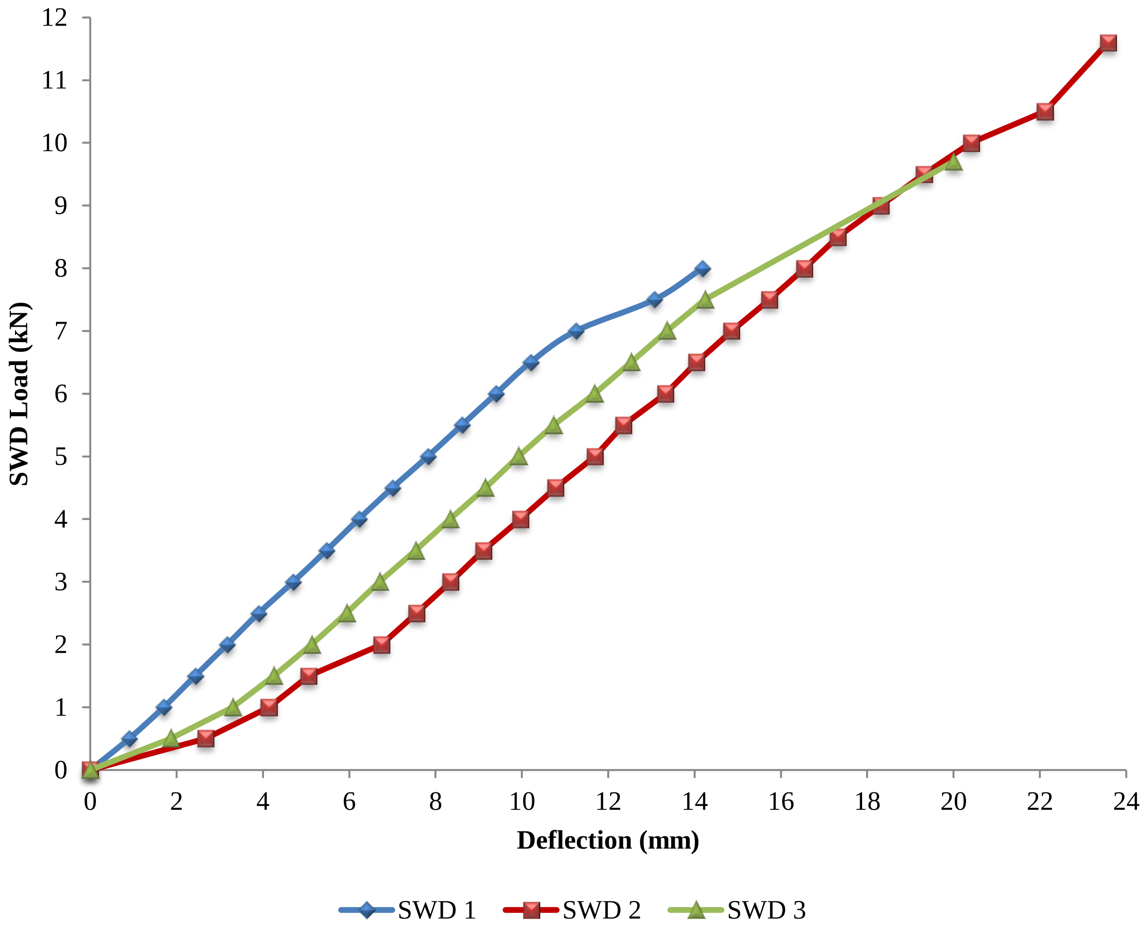

Figure 5.4.1: SWD samples flexural strength results

Figure 5.4.2: SWD plank sample failure mode.

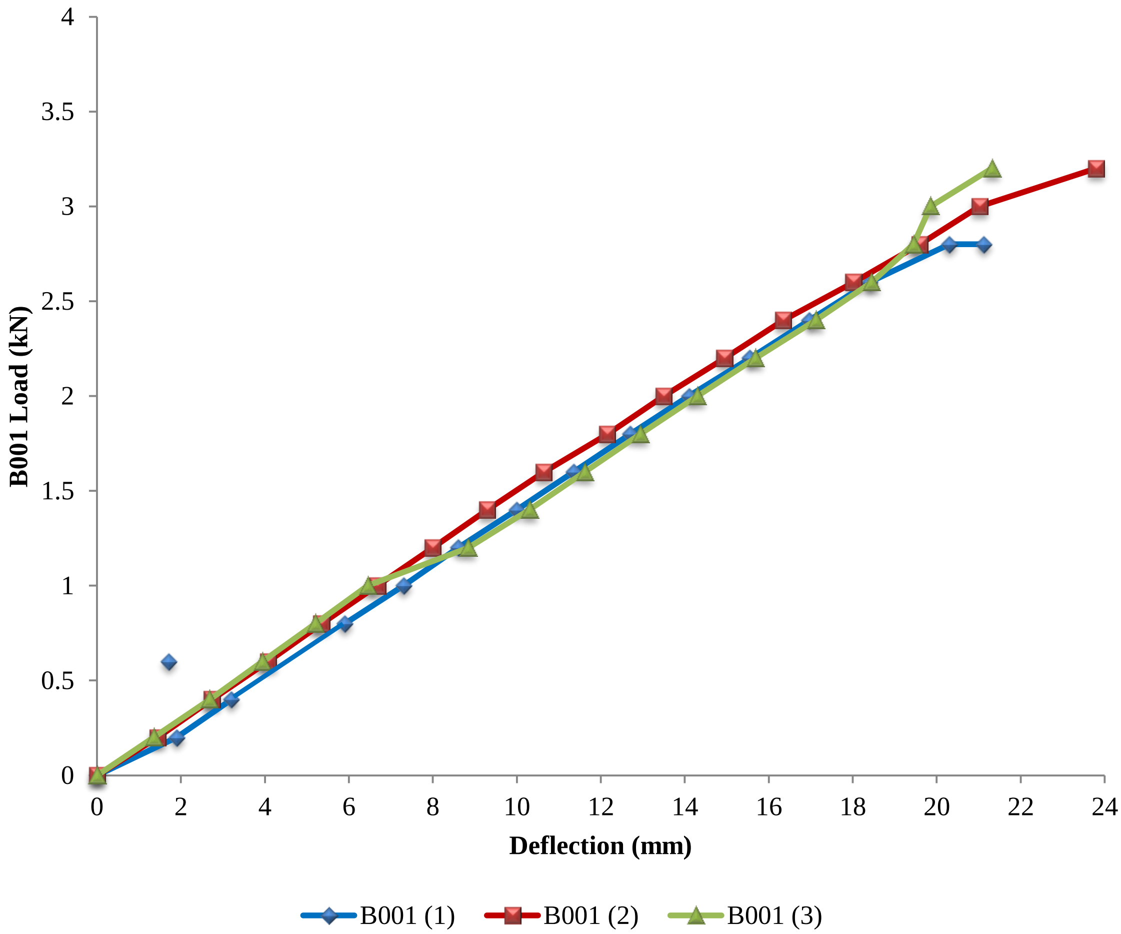

Figure 5.4.3: B001 samples flexural strength results

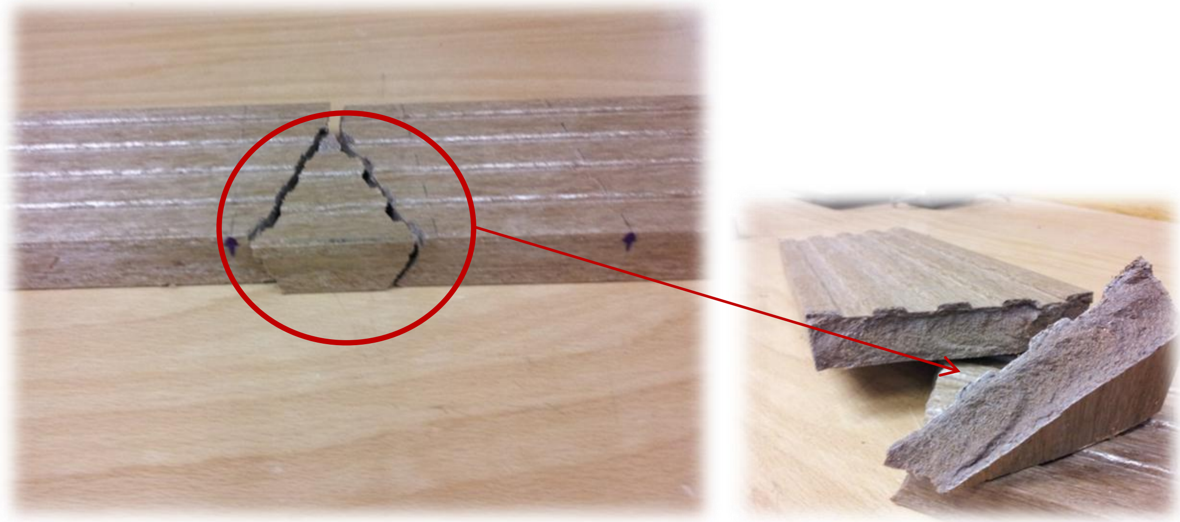

Figure 5.4.4: Brittle failure of polymer sample B001 plank.

Figure 5.4.1 shows the detailed deflection data of SWD planks. The figure shows that the samples have a similar pattern within the load/displacement relationship. Figure 5.4.2 shows the typical failure mode of the material tested. The figure shows that the type of fracture induced in the material due to load bearing does not cause a sudden failure and the material is still held together. This indicates that the stiffness of the material is sufficient to resist deformation of the material in response to the applied force. The failure of this is progressive.

Figure 5.4.3 shows the displacement of the polymer decking (B001) planks. The figure shows that the samples have a linear distribution and show a uniform load/displacement relationship, despite the initial atypical behaviour of sample B001(1) possibly due to human error. Figure 5.4.4 shows the typical failure mode for polymer decking planks. From this figure it can be seen that the type of fracture induced in the material due to load bearing is brittle and as such, does not allow an initial warning that the material is about to fail. The failure of this material is fast and sudden.

Results Comparison

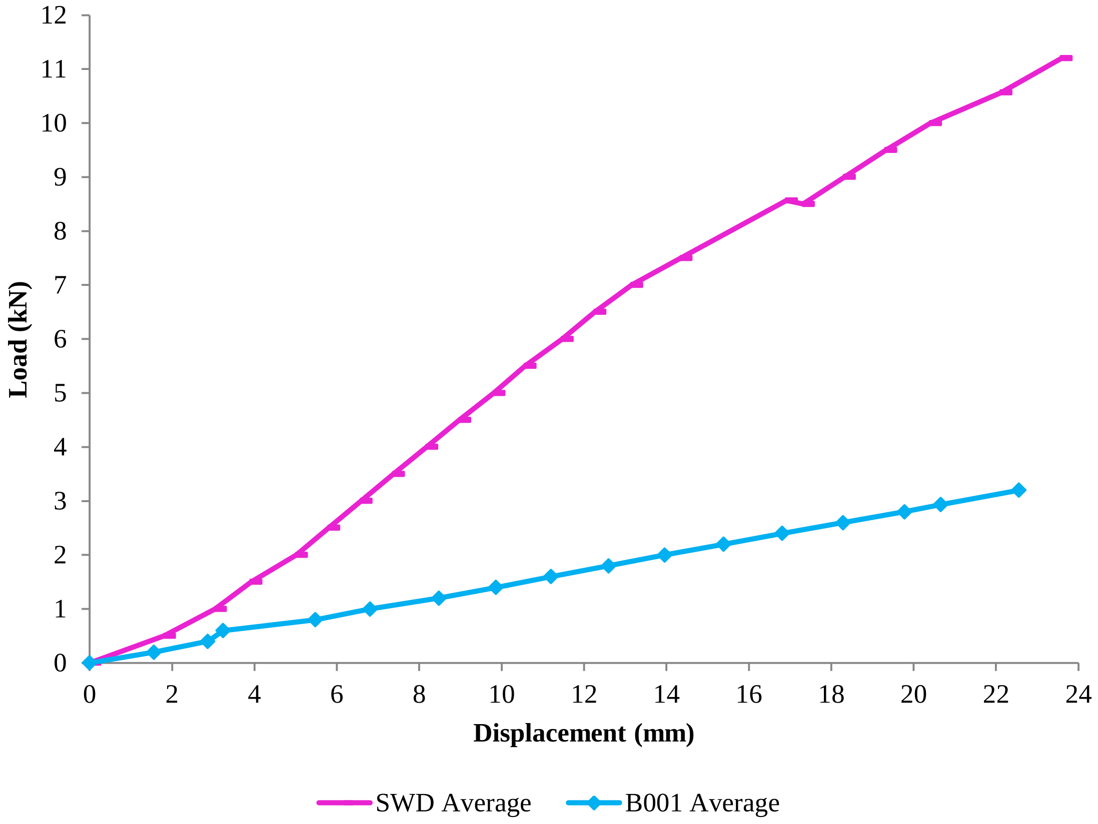

Figure 5.4.5: Comparison of the specimens' bending strength

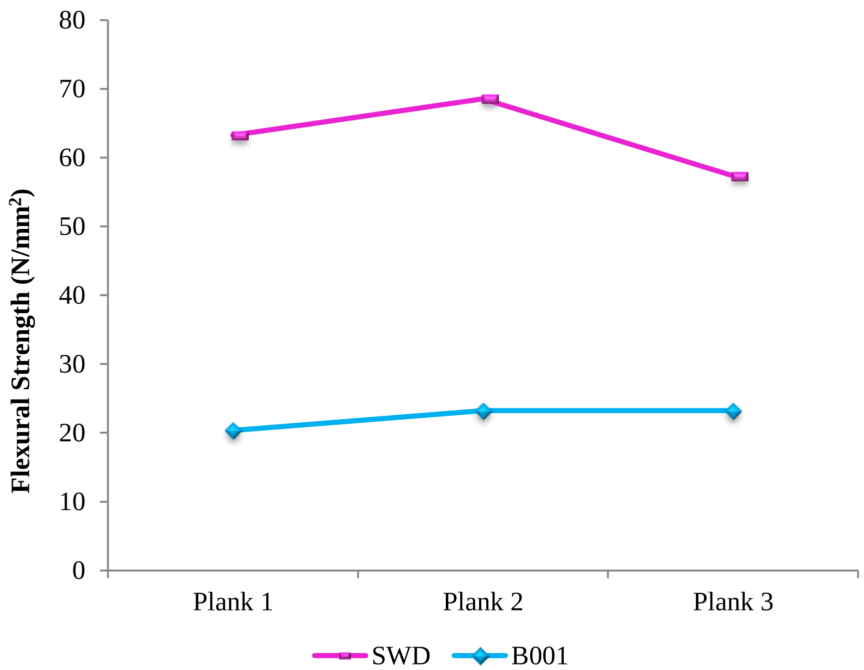

Figure 5.4.6: Specimens flexural strength comparison. (Appendix E)

Figures 5.4.5 and 5.4.6 depict the comparative analysis of SWD and B001. Figure 5.4.5 compares the average displacement of the specimens. From this figure it can be concluded that SWD has an elastic behaviour almost four times higher than the polymer specimen B001. Contrary to SWD, B001 allows a minimal flexural bending due to its brittle characteristic.

Figure 5.4.6 shows the flexural strength comparison of the materials. The values here presented corroborate the results data from compressive strength. The modulus elasticity for the axial plane of SWD was about twice the value for B001. B001 presented an evenly distributed elasticity which accounted for the unspecified/non-existent strong axes.

Summary

From the results comparison, it can be seen that the polymer decking specimen have a lower flexural bending than the wood specimen. During the carry out of the experiment, it was possible to observe that the polymer decking material is brittle and that the failure of material is sudden at moment of rupture. The wood specimen showed a higher ability to resist to deformation and at failure was still able to support the structure above, Figure 5.4.2. Table 5.4.1 results show that the flexural strength of the SWD is about three times higher than B001.

Table 5.4.1: Specimens flexural strength comparison

Specimen	Board 1 (N/mm^2)	Board 2 (N/mm^2)	Board 3 (N/mm^2)	Average (N/mm^2)
SWD	63.24	68.56	57.33	63.04
B001	20.32	23.23	23.23	22.26

5.5. THERMAL CONDUCTIVITY

The results presented in this section are concerned with the ability of the test specimens to transfer heat by conduction. The knowledge of the thermal properties of a material is a vital assessment with regard to designing value specifications for new buildings.

Three to four samples of each specimen were subjected to the test. The conductivity values for the analysed specimens were given from the average of three test samples. Due to unforeseen problems, part of the tests had to be carried out by Gearing Scientific Ltd, in Ashwell Herts, UK. The laboratory tests undertaken by Gearing Scientific Ltd were carried out using Laser-Comp Fox 50 equipment with different procedures from the ones carried out using Laser-Comp Fox 200 equipment.

The data used for the calculations of these results are shown in Appendix F.

Table 5.5.1: Polymer samples B001 samples thermal conductivity (Fox 50)

B001	**Thickness**	**Weight**	**λ @ mean 20^{0}C**
Sample N.	(mm)	(g)	(W/mK)
31	25.3	49.1	0.105
32	24.8	43.7	0.111
33	24.1	53.6	0.103
		Average Conductivity:	0.106 W/mK

Table 5.5.2: Polymer samples B002 samples thermal conductivity (Fox 50)

B002	**Thickness**	**Weight**	**λ @ mean 20^{0}C**
Sample N.	(mm)	(g)	(W/mK)
34	23.2	35.3	0.0786
35	23.3	36.5	0.0788
36	23.5	35.8	0.0755
		Average Conductivity::	0.0776 W/mK

Table 5.5.3: Polymer samples B003 samples thermal conductivity (Fox 50)

B003	Thickness	Weight	λ @ mean 20^{0}C
Sample N.	(mm)	(g)	(W/mK)
37	22.7	36.2	0.0864
38	22.9	42.9	0.0876
39	22.9	45.8	0.0848
		Average Conductivity:	0.0863 W/mK

Table 5.5.4: Wood samples SWD samples thermal conductivity (Fox 50)

SWD	Thickness	Weight	λ @ mean 20^{0}C
Sample N.	(mm)	(g)	(W/mK)
5	23.3	20.1	0.0901
6	28	22.2	0.112
7	23.3	22.8	0.0974
		Average Conductivity::	0.0938 W/mK

Table 5.5.5: Wood samples HWD samples thermal conductivity (Fox 50)

HWD	Thickness	Weight	λ @ mean 20^{0}C
Sample N.	(mm)	(g)	(W/mK)
5	21.2	21.3	0.082
6	26.4	23.2	0.117
7	21.4	25	0.0932
		Average Conductivity:	0.0876 W/mK

Tables 5.5.1 to 5.5.5 show the tabulated results of tests carried out on the specimens by Gearing Scientific Ltd. From these results, it can be seen that the polymer decking B001 display a higher conductivity value. Thermal conductivity is measured in function of the rate of heat flow in response to a temperature gradient. This is influenced by the density of material and the material capacity to conduct heat through its grain particles. This factor influences the results of the wood samples (SWD and HWD), which show the following higher conductivity values. According to the Society of Wood Science and Technology, the thermal conductivity in radial direction (vertical) is equal to the thermal conductivity in tangential direction (transversal) but parallel to the grains (axial) the conductivity value is 2 to 3 times its radial or tangential values. This allows wood to transfer heat flow twice or three times faster.

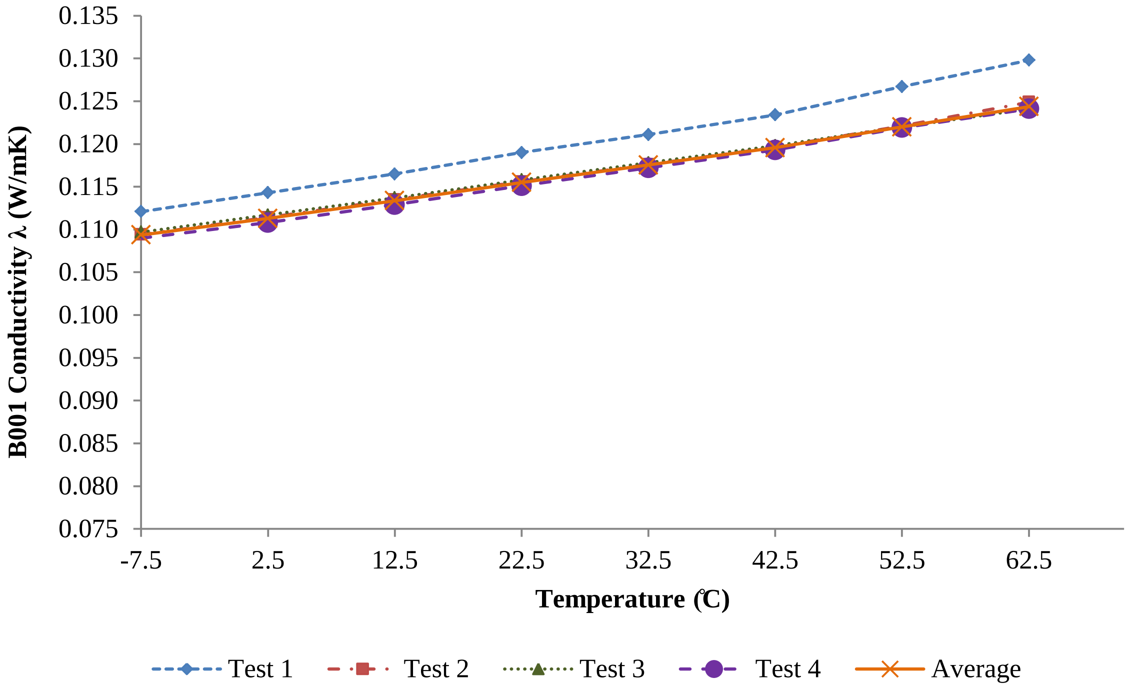

Figure 5.5.1: B001Thermal conductivity against temperature (Fox 200)

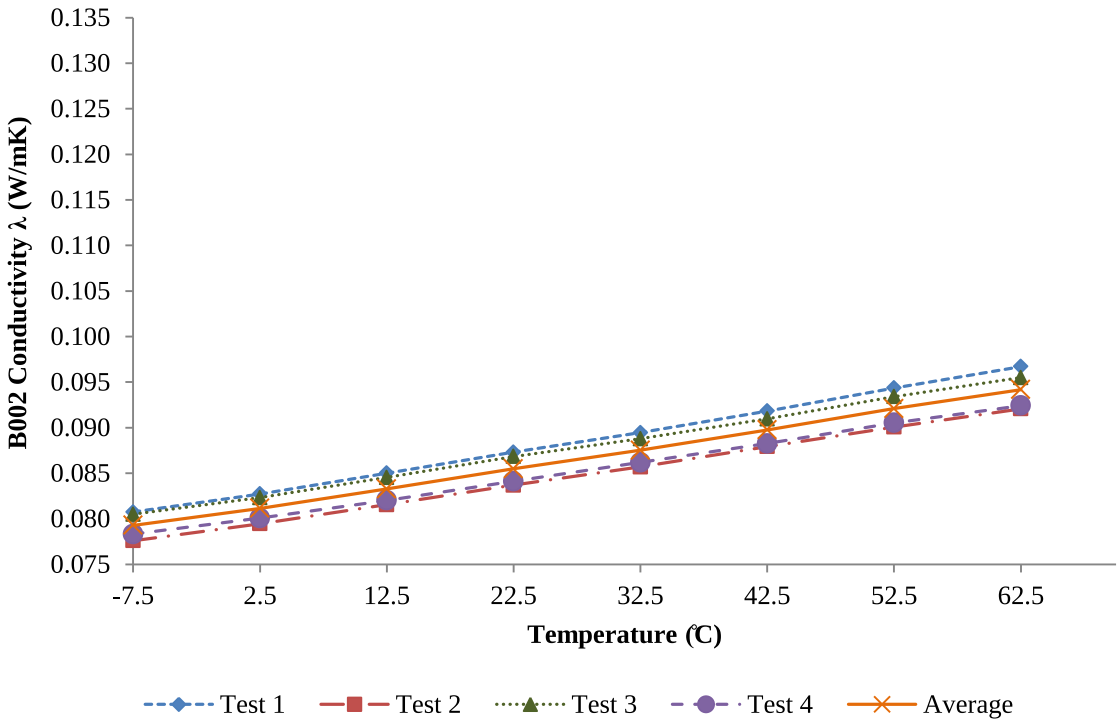

Figure 5.5.2: B002 Thermal conductivity against temperature (Fox 200)

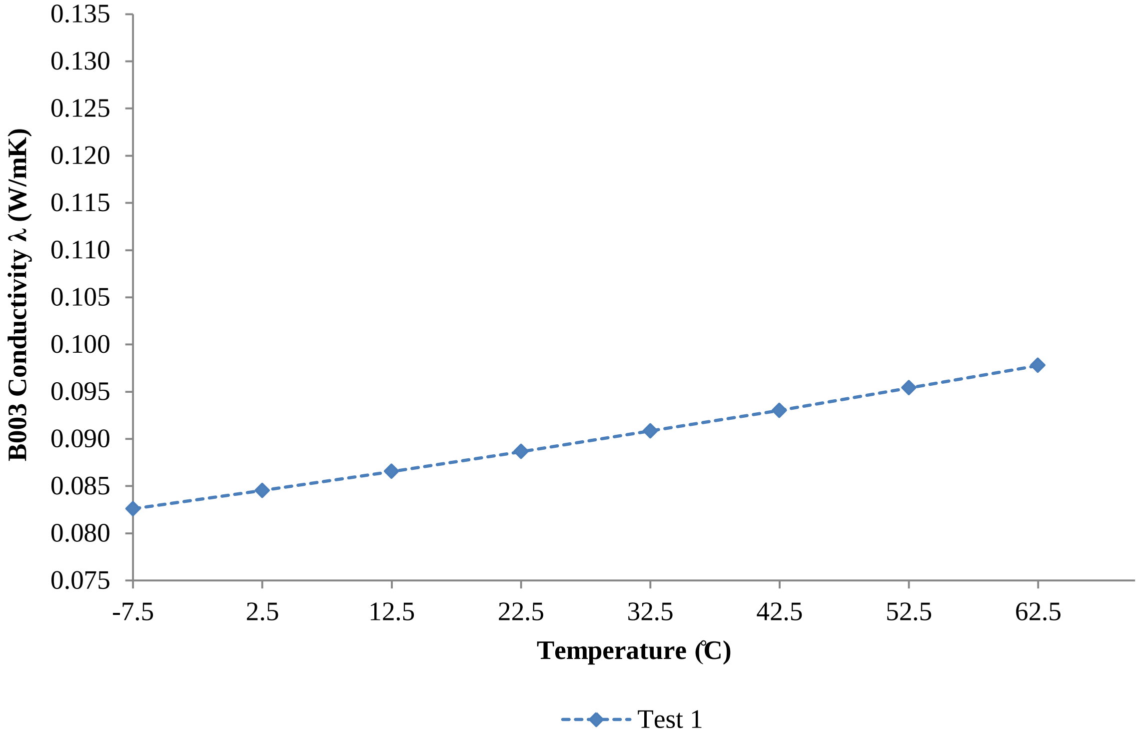

Figure 5.5.3: B003 Thermal conductivity against temperature (Fox 200)

Figure 5.5.1, Figure 5.5.2 and Figure 5.5.3 show the thermal conductivity results, for polymer decking specimens, carried out internally. The overall results indicate that the polymer decking specimens' conductivity ranges from about 0.078 W/mk, at -7.5˚C, to 0.125 W/mk, at 62.5˚C. These figures also show that B002, the less dense specimen has the lower conductivity. This result supports the theory that the density of material and its capacity to conduct heat through are interconnected.

Results Comparison

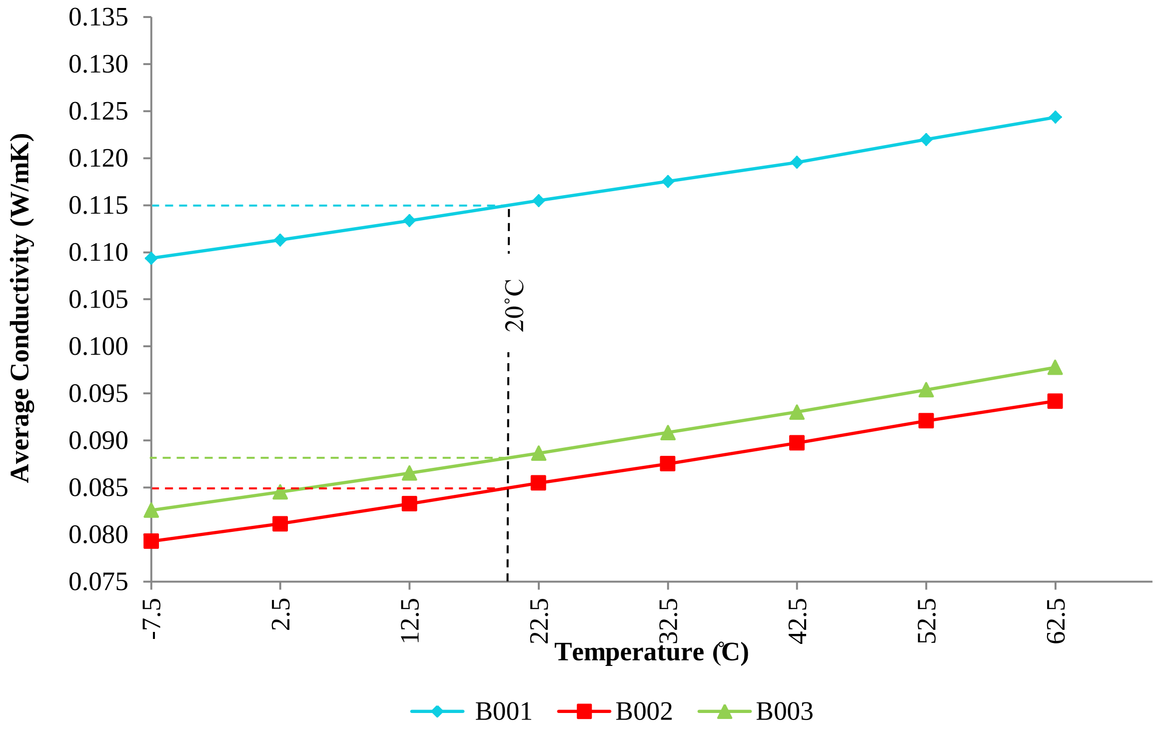

Figure 5.5.4: Mean thermal conductivity (λ) results comparison for tests carried out on Fox 200.

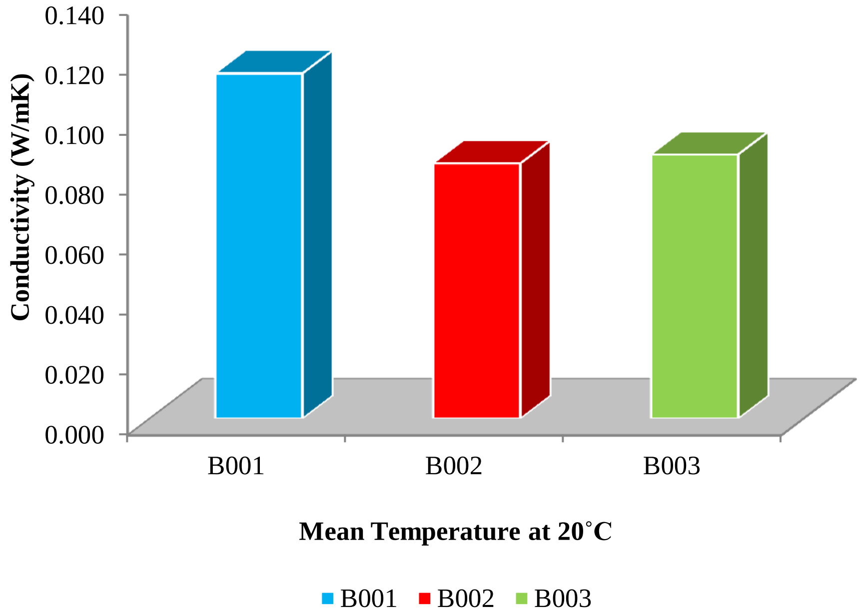

Figure 5.5.5: Thermal conductivity (λ) results comparison for tests carried out on Fox 200, at temperature of 20˚C.

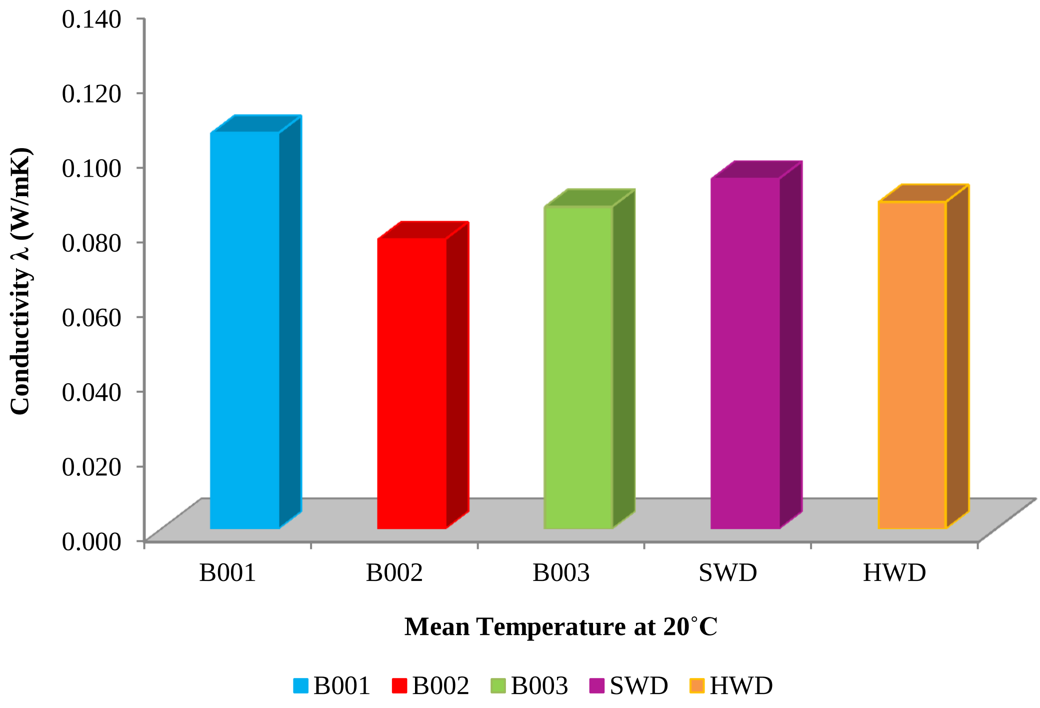

Figure 5.5.6: Thermal conductivity (λ) results comparison for tests carried out on Fox 50, with a mean temperature of 20˚C.

Figure 5.5.4 shows the mean thermal conductivity of the polymer specimens tested internally. In this figure it can be seen that the data shows a similar pattern I the temperature/conductivity relationship. The plotted data shows a consistent behaviour of the specimens. The conductivity values at 20˚C indicated in this figure is used for comparison purposes in Figure 5.5.5.

The thermal conductivity results of Figure 5.5.5 were used for comparison with the data of the tests carried out externally, shown in Figure 5.5.6. Analysing these two figures is possible to conclude that the results shown in Figure 5.5.4 show higher values. This is probably caused by the difference in samples size and thickness, as well as the overall process of data recording. The data shown in Figure 5.5.4 was extracted from a continuous thermal conductivity test with different set point which differs from the methodology used for the results shown in figure 5.5.5.

Summary

Comparing the data obtained from the tests carried out internally and the one carried out externally (Fox 50 equipment (20˚C)) and the correspondent values obtained on the (Fox 200 equipment (20˚C)) it can be seen that although the average conductivity results are not the same for any of the samples, there is a interrelationship within the results as the conductivity results obtained is similar between tests. On both results B002 presents the lower conductivity value and B001 the higher.

From the results comparison of the thermal conductivity of the specimens tested it can be seen that the recorded values for the polymers specimens are dependent of their density. The thermal conductivity of the wood specimens' values presented here are within the values presented by Gupta *et al.*, (2003). The values for thermal conductivity are summarised below, Table 5.5.6 and Table 5.5.7.

Table 5.5.6: Specimens Thermal Conductivity at 20˚C, Fox 50

Specimen	λ (W/mK) at 20^{0}C
B001	0.106
B002	0.0776
B003*	0.0863
SWD	0.0938
HWD	0.0876

Table 5.5.7: Specimens Thermal Conductivity at -7.5˚C, 22.5˚C and 62.5C, Fox 200

Specimen	λ (W/mK) at -7.5^{0}C	λ (W/mK) at 20^{0}C	λ (W/mK) at 22.5^{0}C	λ (W/mK) at 62.5^{0}C
B001	0.109	0.115	0.116	0.124
B002	0.079	0.085	0.085	0.094
B003*	0.083	0.088	0.089	0.098

* Values given by only one sample.

5.6. FREEZING and THAWING

This section shows the effects of freezing and thawing on the specimens in analysis. The specimens were tested under wet and dry conditions with temperatures ranging between 30˚C and -15˚C. The typical freeze-thaw profile used to assess the specimens is shown in

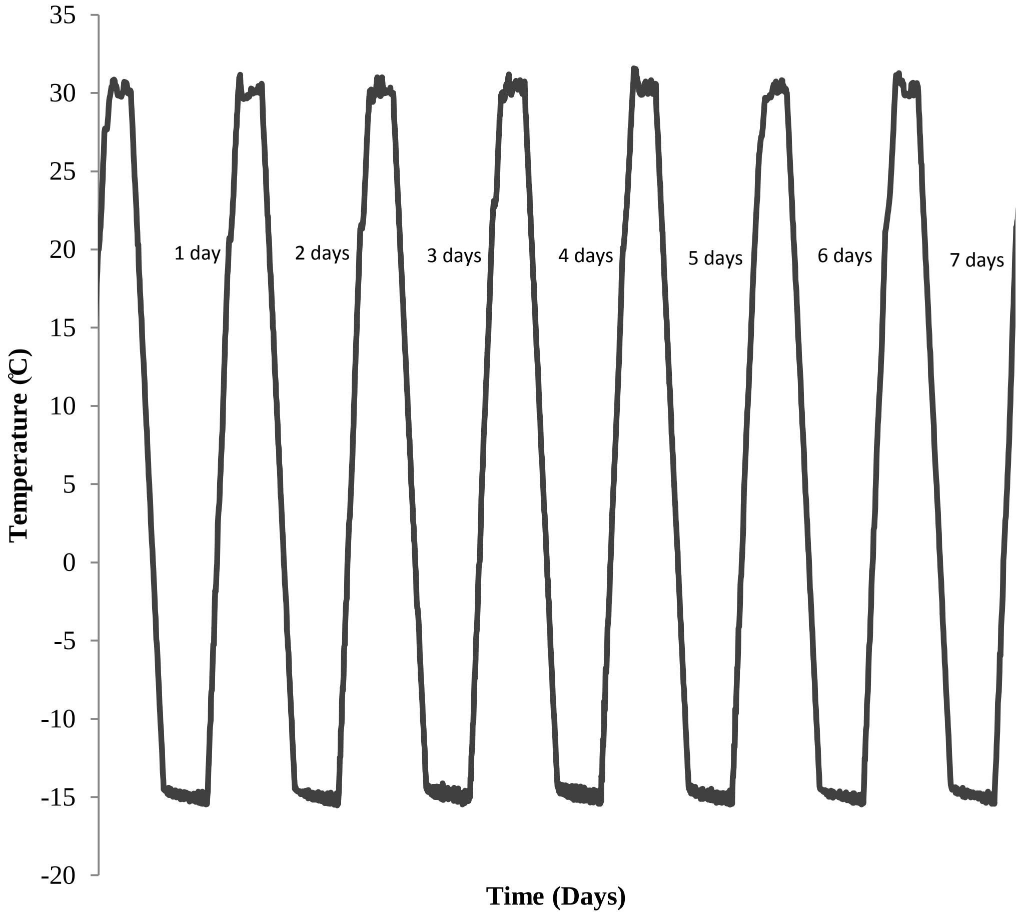

Figure 5.6.1: Profile of seven days of 24 hours freezing and thaw cycle

Dry test

In order to carry out this test two distinct groups ware used. The first, wet specimens soaked in water for a long period of time, and second, dry specimens kept at room temperature. Both control groups, wet and dry specimens, were placed in the climatic chamber. After 28 days of freeze-thaw cycles, wet and dry specimens used for the dry test did not show any visual damages or cracks. There was also no change in width, length or thickness of these specimens, although there was a small percentage of weight loss in all wet specimens. Due to the presence of moisture, a small percentage of weight gain was recorded on the dry wooden specimens (SWD and HWD) used to carry out these tests. Dry polymer specimens did not show any change or variation at all. Figure 5.6.2 gives the depiction of the wet specimens on dry freeze-thaw test and Figure 5.6.3 the depiction of different specimens on dry freeze-thaw test.

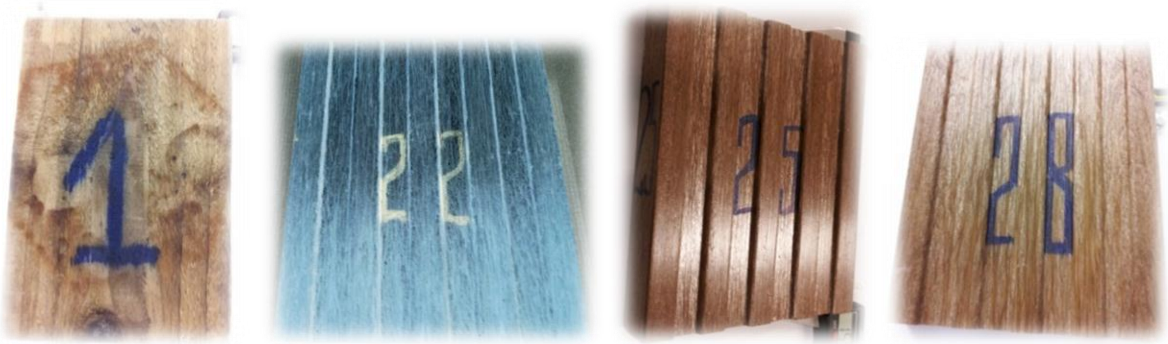

Figure 5.6.2: Depiction the effects of 28 days freeze-thaw cycles on previously wet samples after dry freeze-thaw test. A small percentage of weight loss was detected in all specimens, although no visual damage was detected. (By order: TSW, B001, B002 and B003)

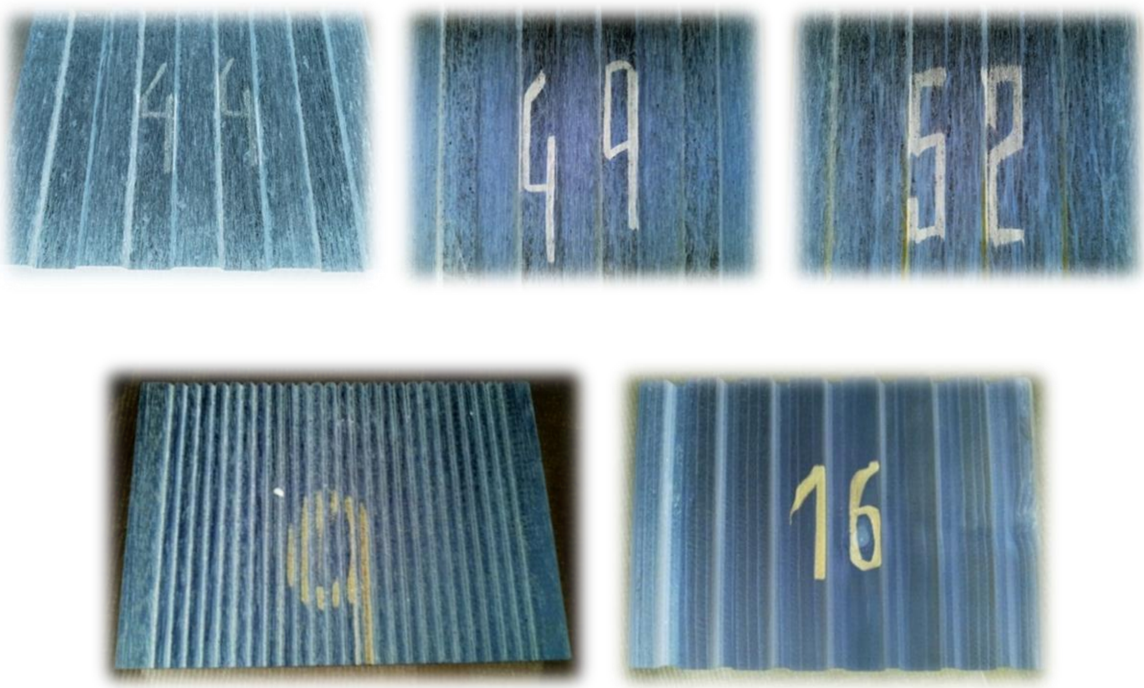

Figure 5.6.3: Depiction of the effects of 28 days freeze-thaw cycles effect on samples after dry freeze-thaw test after. (By order: B001, B002, B003, HWD and SWD)

Wet test

In order to carry out this test, all the specimens were soaked in water, at room temperature for 24 hours, before the commencement of the tests. The specimens were originally dry. After this 24 hours period the specimens were soaked in water inside a metal container, which was placed in a climatic chamber. After 28 days of freeze-thaw cycles, all specimens submerged in water showed changes in weight. The wooden specimens also showed changes on their widths, lengths or thicknesses. After this test it was possible to see visual damages. HWD have expanded in all directions and gained increase in weight of about 80 per cent, due to the presence of moisture, and SWD have also expanded and gained about 70 per cent of increase in weight due to the same reason. Conversely, the variations in polymer specimens were almost inexistent, seeing that B001 had an increase in weight of about 0.9 per cent, B002 had an increase in weight of about 1.45 per cent, and B003 had an increase in weight of about 0.86 per cent. The wooden specimens showed wear on their surfaces while the polymer specimens showed frost depositions, as shown in Figures 5.6.4.

Figure 5.6.4: 28 days freeze-thaw cycle effect on specimens. The sample of higher density shows greater frost effect, wet test. (B001, B002, HWD, SWD, B003)

5.7. DIMENSIONAL STABILITY ASSESSMENT

This section demonstrates the behaviour of the test specimens when exposed to a high temperature, immediately after being submerged in water for a long period of time. Deformation (creep) increases due to changes in humidity and temperature. The stress induced by thermal expansion (termed swelling or shrinkage), is commonly caused as a result of micro diffusion of water or air between capillary pores and /or gel pores. The rate upon which this diffusion occurs induces breakages that affect the tensile cracking and are the source of creep.

In wood, the thermal expansion has occurred extensively under dry or moist conditions but measurements under water saturated conditions have been less consistent. Shrinkage caused by moisture loss is greater than thermal expansion, so the dimensional change is negative. This is because the wood initially expands and then gradually contracts to a volume smaller than the initial volume as the wood gradually loses water while in a heated condition.

The shrinkage caused by moisture loss on heating is usually greater than thermal expansion, so the net dimensional change on heating would be negative. Wood at intermediate moisture levels would expand when first heated, and then gradually shrink to a volume smaller than the initial volume as the wood gradually loses water while in a heated condition.

In a polymeric material the thermal expansion increased with a discontinuity, both at the glass transition. Under this condition some polymers show a high thermal expansion when heated. Usually, this phenomenon can be found in linear polymer behaviour, where the coefficient of thermal expansion varies. With an increase of the amount of cross-linked bounds, the magnitude of the coefficient of expansion decreases.

The specimens used for this laboratory experiment were submerged in water for about five to seven months, with the exception of SWD and HDW that have only been submerged in water for 28 days before the experiment. The variation in weight and dimension can be seen in Appendix G. On this appendix it can also be noted that at 70˚C some samples did not recover their initial weights (B001, B003 and TSW) which means that they were not fully dried. The following tables and figures show the profiles of each material under the characteristics mentioned above.

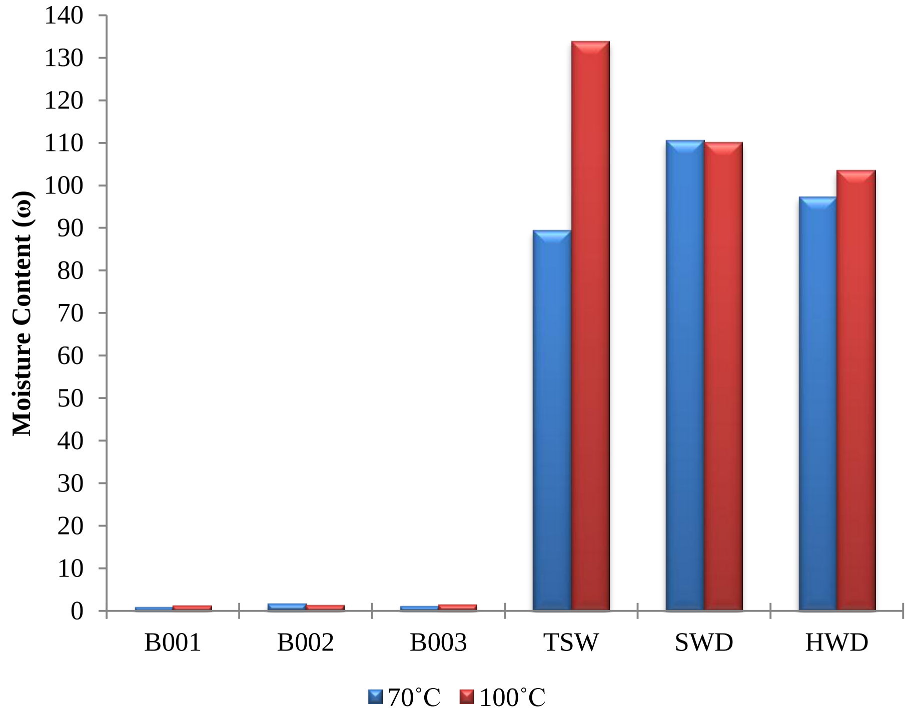

Figure 5.7.1: Percentage of moisture loss, comparison of polymer and wood specimens'.

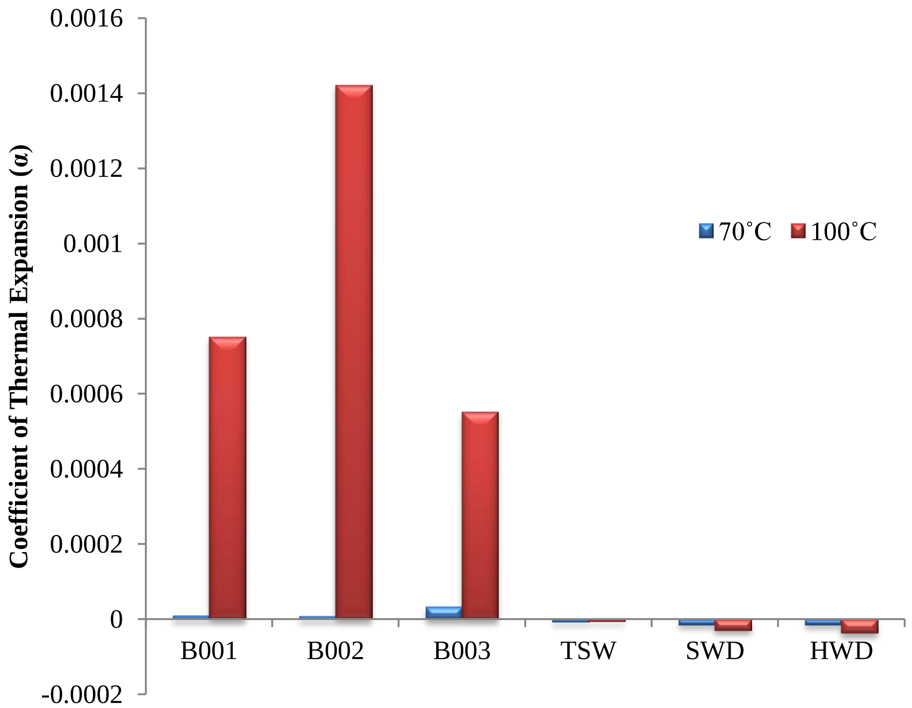

Figure 5.7.2: Coefficient of thermal expansion of polymer and wood specimens'.

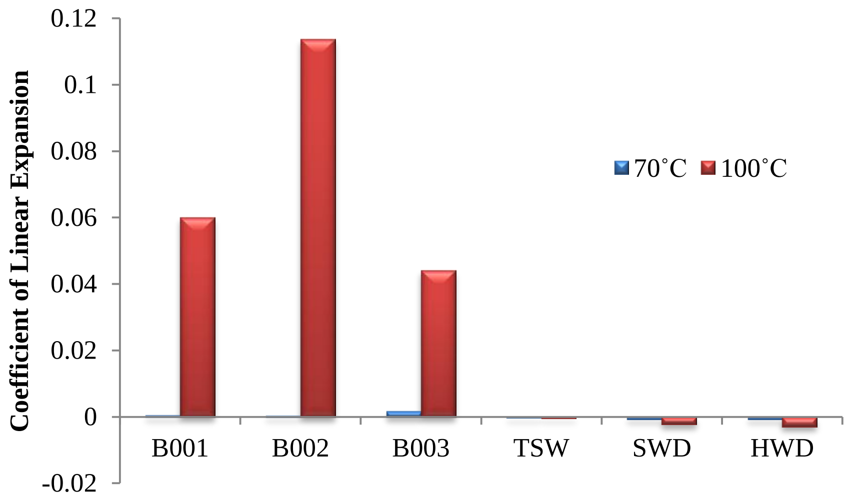

Figure 5.7.3: Coefficient of linear expansion of polymer and wood specimens'.

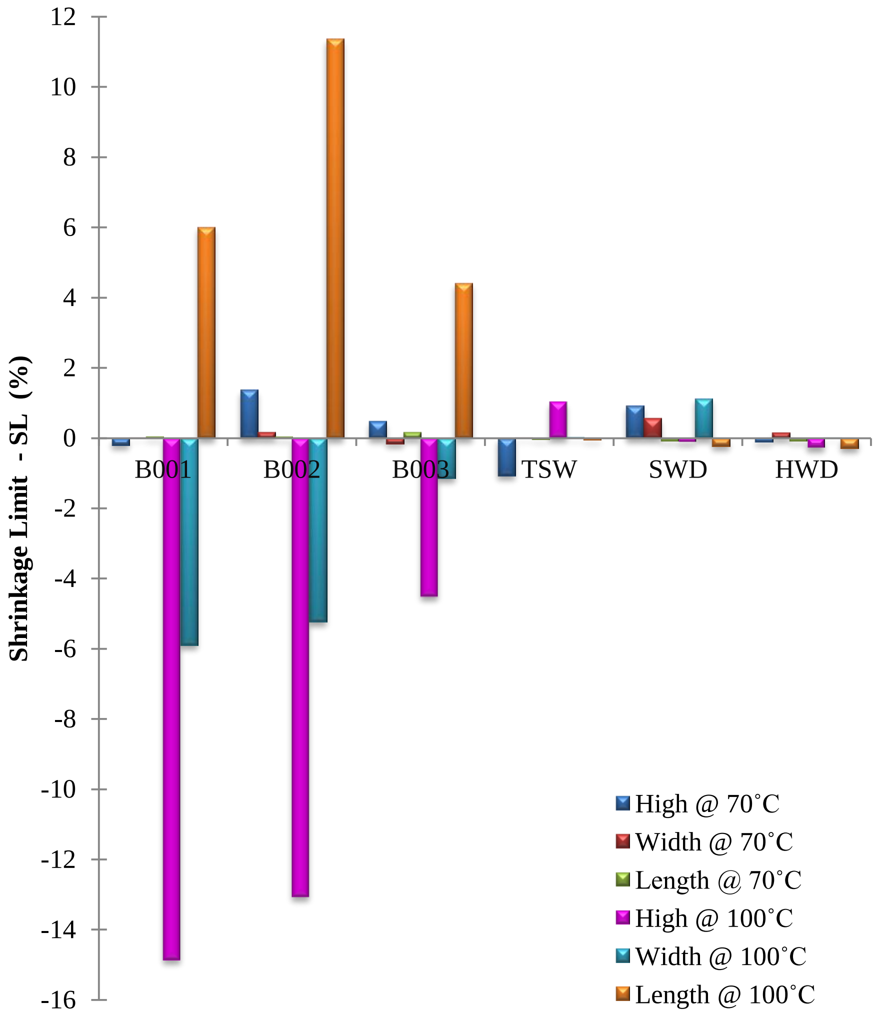

Figure 5.7.4: Shrinkage limit, behaviour of polymer and wood specimens' according material (positive concerns to contraction and negative concerns to expansion).

Figure 5.7.1 shows the percentage of moisture loss of the samples, at 70 and 100˚C. In this figure it can be seen that the polymer specimens show a negligible content of moisture loss. This factor is related to the rate of water absorption of the materials. This figure shows also that the moisture content of the wood specimens' very high, above the threshold of 100%. This factor might be related to the fact that the samples were continuously submerged in water and became oversaturated. The considerable discrepancy between TSW at 70˚C and TWS at 100˚C can be related to the long period of time that the sample was submerged in water and to the fact that at 70˚C degree this specimen was not completely moisture free, see Appendix G.

Figure 5.7.2 shows the coefficient of thermal expansion of the specimens. Is this figure is possible to observe that at 70˚C the coefficient of thermal expansion is minimum for both, wood and polymer specimens. At 100˚C the polymer samples show a certain degree of expansion on its particles. This is related to the characteristic of the material in change to glass transition when heated above 90˚C, see Figure 5.7.5 and Figure 5.7.7. The same figure shows that the coefficient of thermal expansion of wood specimens remains unaffected at this temperature. In the same way, for the coefficient of leaner expansion shown in Figure 5.7.3, polymer and wood specimens' show similar behaviour. In both situations B002 is the sample more affected by heat.

Figure 5.7.4 shows the shrinkage limit of the specimens in analysis. B001 shows an insignificant percentage of shrinkage at 70˚C but a high changes regard to 100˚C. At this temperature the change in value of the thickness expands about 15%, and both, width expand about 6% and shrinks about 6% in length. B002 shows some percentage of shrinkage at 70˚C but the substantial changes occur at 100˚C. Both thickness and length of B002 show more than 10% change in their dimensions. The thickness swell about 13%, length shrinks about 12% and the width swell about 5%. B003 is the polymer specimen that shows fewer changes. At 70˚C the thickness shows a relative small change. At 100˚C B003 shrinks about 5% in length and swell about the same in thickness the change in width is of about 1%. Figures 5.7.5 and 5.7.7 give the visual depiction of this data. With regard to wood specimens' TSW only show changes in thickness, the sample swelled about 1% at 70˚C and shrink about the same at 100˚C. With regard to SWD showed some contraction in width at both temperatutes and as well as small contraction in thickness at 70˚C. HWD showed insignificant variations at both temperatures. The effect of heat in the wood specimens caused cracks in the specimens, see Figure 5.7.6.

Figure 5.7.5: Thermal contraction of polymer specimens' (B001, B002 and B003) at 100˚C.

Figure 5.7.6: Shrinkage effect of wood specimens' (SWD, HWD and TSW) caused by moisture loss by heat at 100˚C.

Figure 5.7.7: Comparison between samples tested at 70˚C and 100˚C.

Summary

The stability of all specimens was affected by moisture, although each material behaved differently, and according to their natural properties. SWD oven dried samples (100˚C and 70˚C) have shown considerable amount of micro cracks on all their plan sections. The samples had previously crack "plans" that expanded/open when the SWD samples were dried in the oven. HWD oven dried samples (100˚C and 70˚C) showed no visual changes or cracks. The main visible change concerns the fact that after being oven dried it was possible to see the radial annual growth rings in the transverse section of the samples. From the data results on Appendix G it can be seen that the samples were not completely dry after 24 hours in the oven at 70˚C.

At 100˚C polymer decking specimens behaved overall in the same way contracting, B002 samples showed accentuated contraction and also a bending curvature on its horizontal plan. All samples expanded their thickness as well but batch B003 showed less changes. At 70˚C the polymer specimens showed small changes on the thickness of the samples, especially on B002. Overall this tests shows how susceptible both materials are to external factors, polymer specimens to high temperatures and wood specimens to moisture and heat, resumed below.

Table 5.7.1: Specimens percentage of moisture content loss

	70˚C	100˚C
B001	0.976	1.271
B002	1.795	1.386
B003	1.125	1.584
TSW	89.489	133.977
SWD	110.595	110.150
HWD	97.390	103.649

Table 5.7.2: Specimens Shrinkage limit

	High 70˚C	Width 70˚C	Length 70˚C	High 100˚C	Width 100˚C	Length 100˚C
B001	-0.20	0.01	0.05	-14.85	-5.89	6.01
B002	1.37	0.17	0.04	-13.06	-5.22	11.37
B003	0.49	-0.15	0.17	-4.51	-1.14	4.42
TSW	-1.07	0.02	-0.03	1.03	0.03	-0.04
SWD	0.93	0.56	-0.07	-0.11	1.13	-0.22
HWD	-0.09	0.17	-0.07	-0.28	0.01	-0.29

5.8. EFFECTS of WEATHERING

For this experiment three samples of each specimen (B001, B002 and TSW) were exposed to weathering processes. This process started in June 2012 and continued for a total of eight months, providing the effect of external elements such as sun, rain and snow. After exposition, samples of both specimens (B001 and B002) show an initial formation of green slime in the corners and cutting planes, Figure 5.8.1. Samples of both specimens have also lost their glossy appearance, however the original appearance was restored after the samples were cleaned. After exposition, TSW samples show an apparent lighter colour and an initial formation of green slime although in less amount than the polymer specimens, Figure 5.8.2. This is perhaps due to the porosity of the timber material. TSW samples show also white stain, possibly due to bacterial effect. The labels identification has faded in all samples especially on the surfaces exposed to weathering, although they are still visible on TSW samples.

Figure 5.8.1: Effect of weathering on polymer, after 8 months. (B001 and B002)

Figure 5.8.2: Effect of weathering on TSW, after 8 months of exposure.

Table 5.8.1: Specimens weight after 8 months exposure

Specimens				
B001	**Sample N.**	**4**	**5**	**6**
	Weight (g)	351.29	360.65	388.07
B002	**Sample N.**	**10**	**11**	**12**
	Weight (g)	296.70	295.88	298.93
TSW	**Sample N.**	**4**	**5**	**6**
	Weight (g)	548.41	558.71	461.17

Both polymer specimens did not show any relevant increase in weight after being subjected to weathering process suggesting that no water has been absorbed, wich corresponds to the observation made on the water absorption results. TSW samples have doubled in weight which clearly shows a high rate of water absorption. After 21 days of being kept on the desiccator cabinet (7 days at 25˚C and the remain 14 days at 40˚C), TSW samples showed a reduction in weight due to a reduction in moisture content, however, the samples did not recover to initial values and formation of some cracks was observed. The fact that TSW did not recover the original weight suggests that moisture from weathering process was still present. Similar findings were observed on TSW samples submerged in water for a long period of time, and used as samples for the dimensional stability analysis, TSW value on Figure 5.7.1.

5.9. FIXTURES and BONDING CHARACTERISTICS

The aim of this experiment was to identify the characteristics of bonding and fixtures of the specimens in analysis (B001, B002, B003, SWD, and HWD). For these tests, cube samples of the each specimen were used.

At first the specimens were cleaned with a dry cloth to remove dust and impurities. The specimens were then bonded together with wood adhesive “EVO-STIK”. During the bonding procedure pressure was applied manually to remove extra adhesive from the samples. The following procedure was to leave the samples at room temperature for 24 hours so that the adhesive material would dry completely and therefore the bonding of the specimens would be achieved.

Different combinations of the specimens were bonded together in order to cover any possibilities and to achieve a better understanding of how exactly the bonding of these specimens occurs. This experiment served as an attempt to observe if stronger bonds were achieved between samples of the same specimen and the adhesive (HWD to HWD, SWD to SWD, and polymer decking to polymer decking (B001, B002, B003)).

The final step was to manually apply force towards all directions (bending, buckling, tension and torsion) to verify the characteristics of the bending. All the combinations to bond the specimens with wood adhesive “EVO-STIK” have been successful except the combination of Polymer with Polymer, see Figure 5.9.1. In this case, the polymer decking material did not allow the adhesive to dry or be absorbed, which was why the wood adhesive did not bind the material together. The other combinations of Polymer with Wood have been able to sustain considerable amounts of manually induced load and up to date are still solid and any attempt to separate those has been unsuccessful.

Figure 5.9.1: Specimens bonding combinations.

5.10. ENVIRONMENTAL IMPACT PROFILE

Environmental Impacts EPS

Eco-balances and life-cycle analysis (LCAs) have demonstrated that expanded polystyrene (EPS) has exceptional value as a construction material. EPS brings considerable energy and resource saving benefits and by uses less than 0.1 per cent of global oil as a feedstock. This represents a reduction of about 200 times its own resource in thermal energy saving. EPS manufacturing units do not produce residual solid waste from the production process and since the material is made of almost one single material the process of recycling can be made in the same industrial plant relatively easy.

The inherent lightweight of EPS makes it the lightest of all construction materials in common use as it helps to minimise environmental impacts and costs associated with the transportation of heavier materials. EPS makes use of no chlorofluorocarbons or hydro-chlorofluorocarbons in manufacture, it has zero ozone depletion potential and a low global warming potential and all emissions are controlled strictly within environmental regulatory frameworks which apply in the UK and EU.

EPS gets the highest possible A-Plus summary rating in the Building Research Establishment (BRE) Global Green Guide to Specification when used for construction applications, factor that makes EPS one of the special groups of construction materials which have the least possible environmental impacts. In addition to the A–Plus summary rating, EPS (rated on element no. 815320022) gains ‘A’ ratings across the majority of the critical environmental performance matrices including: mineral resource depletion, human toxicity, ecotoxicity, waste disposal, fossil fuel depletion, acidification, water extraction (BRE, 2008).

In its original state EPS has outstanding thermal insulation qualities which make it a first choice material for many construction applications. EPS reduces CO_2 emissions by up to 50 per cent, making sure that it more than compensates its small carbon footprint, giving maximum return for minimal resource and by acting as a highly efficient thermal insulator. EPS has extremely low moisture absorption and will never rot. Together with its outstanding ageing performance and chemical resistance, it offers good durability. EPS is 100 per cent recyclable since it does not degrade or deteriorate. During production, all manufacturing waste can be fully reprocessed by milling or granulating into pellets and adding to the production mix without any detriment to the quality of the finished EPS product.

Environmental Impacts of Timber

Reports from the BRE's extensive research into the environmental profiles of building materials have reinforced timber's claim as the 'green' building material of choice. The results have shown clear environmental advantages for timber, particularly in the impact field of climate change where timber's low embodied energy and carbon storage properties actually give it a positive impact, and is expected to change the 'carbon neutral' expression that is used to describe timber . This applies even when taking account of the CO_2 released through its transportation and processing.

The UK uses around 40 million m of timber every year, of which approximately two thirds is imported. Such imports come from tropical and non-tropical forests all over the globe. Whilst wood and forests are clearly associated with pure environmental concerns, a wide range of social and poverty issues are also associated with the growing and production of forest products. The advantages of using wood are related to versatility, aesthetics, properties such as the high strength /weight ratio, workability, recyclability, and the fact that timber is a renewable resource.

As with any other waste resulting from manufacturing processes, wood waste is dealt with under the IPCC regulations, which concerns the release of polluting substances to air, land and water. Wood waste is traditionally disposed of in landfill with some sent for combustion, and this results in only a small amount of wood waste being recycled and creates difficulties at the point of disposal with contaminants and the need to control emissions. Research work is currently being carried out at TRADA aims to identify ways of sorting sources of wood waste to make better use of clean waste. In terms of specific gas emissions, the manufacture of timber products is associated with lower emissions of CO_2, carbon monoxide (CO), sulphur dioxide (SO_2), hydrocarbons and volatile organic compounds.

Embodied energy of EPS and Timber

The embodied energy of a building material can be taken as the total primary energy consumed (carbon released over its life cycle). Ideally the boundaries would be set from the extraction of raw materials, including fuels, until the end of the products lifetime including energy from manufacturing, transport, energy to manufacture capital equipment, heating and lighting of factory, maintenance, disposal known as 'Cradle-to-Grave'.

It has become a common practice to specify the embodied energy as 'Cradle-to-Gate', which includes all energy, in primary form, until the product leaves the factory gate. The final boundary condition is 'Cradle-to-Site', which includes all of the energy consumed until the product has reached the point of use.

The embodied energy is measured in megajoules per kilogram (MJ/kg) so it is important to take into account the density of the material. For instance expanded polystyrene has very high embodied energy but is very light so using it for insulation is not as bad as it might initially seem, timber is low and has the added bonus of locking up carbon for the duration of the building's lifetime.

Table 5.10.1: Values of embodied energy and CO_2 for timber and EPS (Source: Hammond and Jones, 2011)

Material	Energy (MJ/kg)	Carbon kg (CO_2/kg)	Density (kg/m^3)
Timber (general)	10.00	0.72	480-720
Expanded Polystyrene (EPS insulation)	88.60	2.55	15-30

In general it could be stated that there are good LCA for results both EPS and timber, making them both environmental conscious materials. EPS is also suitable for thermal recycling. Being produced originally from petroleum, EPS generates heat energy as much as heavy oil (40.20MJ/kg) and so is also suitable for the thermal recycling to utilize as heat energy efficiently, and it is far better than the traditional use of wood. EPS generates heat energy of 40.20MJ/kg while wood generates heat energy of 18.84MJ/kg.

CHAPTER 6
DISCUSSION
CONCLUSIONS &
RECOMMENDATIONS

This chapter discusses the laboratory work, the observations made, the correlations between observations and the overall practical implications. This chapter regards also the conclusion and recommendations for further work.

6.1. DISCUSSION

The global and steady increase of standards of living and the growth in demand of consumer goods, energy and mineral resources have been raising concerns with regard to the needs of our society. The demand for selected materials and the growth in population living on finite resources have been affecting resource security of many countries, due to the severe stress imposed to ecosystems. The present trends have been brought into question with relation to their capacity to nourish, regenerate and maintain, taking into account environmental and developmental aspects.

For instance, the rapid industrialisation and economic development have accounted for more resources being used to meet societal demands. In the last 60 years plastic/polymers consumption has increased much more than the world average, nowadays accounting for a consumption of about 100 million tonnes per year. To a great extent, building and construction industries are environmentally responsible for these trends seeing that these industries are one of the largest end users of this resource.

A correct selection of a building or construction material should always be made taking into account the whole life cycle of the material and its environmental impacts. Impacts should be considered over a complete life time and classified in terms of resource use reduction, environmental impacts minimisation; good recycle potential, rational use of resource and energy efficiency, and at the same time reduce or eliminate waste generation. Our survival is ultimately related to these factors and our ability to transform the built environment in ways to reduce the scale of resources flow and its corresponding impacts.

Worldwide the flow of materials has been growing with the expansion of the economy and concerns related to resource use has resulted in an increase of embracing measures to mitigate impacts of production and production patterns, resulting in a more efficient use of materials. The demand for environmentally friendly products and sustainable building have provided for challenges and opportunities with regard to the use of materials. The new paradigm "waste equals food" has become the model to implement environmentally sound strategy to prevent and control production and consumption patterns.

The stress imposed by the rapid industrialisation and economic development on natural resources can be minimised by plastic waste recycling, which provides the opportunity of disposing waste in the most environmentally friendly way, converting it into resource. Building and construction industry are one of the major consumers of polymers, and a potential consumer for recycled plastic products. The growing concern with regard to municipal solid waste (MSW) disposal, the increase consumption of polymer products, and the public awareness of environmental issues makes imperative the adoption of active inclusion of recycled polymer in construction industry. Nevertheless, the main challenges are still related to the efficiency in use, greater reuse of materials, lower maintenance and their durability.

This research work investigates the use of recycled polymer as wood-substitute for sustainable building and construction applications. The material under investigation makes use of recycling and remanufacturing of waste expanded polystyrene (EPS), reprocessing it into a new material for building and construction industry. After the process of remanufacturing, the recycle polymer material is used in solid state. The recovery of the material addresses minimisation of detrimental flow of waste and resource scarcity, having in mind a cradle-to- cradle assessment, eco-efficiency, resource availability and waste management.

The research was focused on assessing the mechanical and engineering properties of the material as well as the general benefits of its usage in building and construction industries. Polymers are expected to lose some of their characteristics due to recycling process. As so, the basic engineering properties of the polymer material are dependent on factors that include the properties of the "raw" materials used, the implications of its usage and overall sustainable approach. This includes, the specimens' voids ratio in the cross-section, the way the material behaves under a certain rate of load applied, the influence of heat, moisture, radiation, pollutants and bacteria. All these factors highly influence the performance of the material studied.

The tests carried out in this study examined the engineering properties of three polymer decking specimens (B001, B002 and B003), two wood decking specimens (SWD and HWD) and a typical soft wood plank (TSW). The tests conducted on specimens include density, rate of water absorption, compression, flexure, thermal conductance, freeze-thaw, dimension stability, effects of weathering, bonding and fixtures, as well as an overall analysis to the environmental impact of the material.

The variations between the polymer and wooden specimens were large, although all specimens showed variations among replicate samples, even when test parameters were controlled. The major findings were related to the water absorption, stiffness, strength and weathering effects in the specimens.

Density and Water Absorption

From the results obtained on the experiments it can be observed that the density values, the rate of water absorption and the compressive strength of the specimens are highly related. Polymer specimens have shown higher densities than wooden specimens. The density of the polymer specimens' was found to be almost double of that of the wood specimens, ranging between 680 to 850kg/m^3. The densities of the wooden specimens (TSW, SWD and HWD) ranged between 380 and 440kg/m^3, about half of the density of the polymer specimens. Within the polymer specimens', B001 shows the higher density and B002 the lower, with more than a 150kg/m^3 difference between them. The density variation of the wood specimens was found to have about 50kg/m^3 between them, with the lower density value corresponding to TSW and the higher to HWD.

Similar to the density results, the rate of water absorption of polymer and wood specimens highly differ from one another. The results show that after being in water for about 14 days the polymer specimen do not absorb water, rather expelling it and swell to a certain minimal extent, see Figure 5.2.12. The polymer specimen of lower density (B002) is the presenting a higher values for moisture absorption and swell, nevertheless the value is negligible. With regard to the rate of water absorption of the wood specimens, all specimens show high rate water absorption. At the same period of time of the polymer specimens (14 days) all wood specimens had absorbed more than 50 per cent of moisture. In these results is also visible that the specimens with lower density absorbs more moisture, although in the case of B002 the specimen is also the one the higher expansion value.

Compressive Strength

Compressive strength parameters are of upmost importance with regard to the durability of the structures to bear load. From the experimental results, it can be seen that the compressive strength in the polymer specimens varies. B001 presents similar results to the ones of SWD and HWD, between 45 and 54N/mm^2 along the axial plan, the values differ with regard to vertical and transversal plans, where B001 keeps a high vertical compressive strength value, of about 47N/mm^2, and a reasonable transversal compressive strength, of about 33N/mm^2. The corresponding compressive strength values for SWD were of about 3.5N/mm^2 for the transversal plan, and 6.5N/mm^2 for the vertical. Equally, the corresponding compressive strength values for HWD were of about 6N/mm^2 for the transversal plan, and 10.5N/mm^2 for the vertical. The remaining polymer decking showed lower values with regard to axial plan compressive strength, ranging between 29 and 41N/mm^2. However, higher values than the SWD and HWD were found with regard to transversal plan, ranging between 16 and 41N/mm^2, and the vertical plan, between 19 and 43N/mm^2. B002 and B003 showed more variation/discrepancy on their results. The overall strain results for the specimens showed that polymer specimens suffer higher deformation when load was applied. The modulus elasticity was calculated with the results obtained from this experiment. Wood specimens were found to have a higher axial elastic modulus, almost double of B001 and more than double of B002 and B003. Polymer specimens were found to have a more even distributed load capacity, due to the particle grains size, which impact negatively overall performance of the material. These findings raise some concerns with regard to performance of the polymer samples under excessive creep, due to constant load which may lead to failure of the material.

Flexural Strength

The flexural strength analysis is a key engineering parameter to identify the materials ability to withstand deformation under load, as the flexural strength represents the highest stress experienced within the material at its rupture moment. This experiment was only carried out with SWD and B001 specimens. From the experimental results it was possible to observe that the polymer decking specimen is stiffer than the wood specimen and inflexible. During the experimental tests it was possible to observe that the polymer decking material is brittle and that the failure of material is sudden at the moment of rupture. Contrarily, the wood specimen showed a higher ability to resist deformation. The flexural strength of the SWD was four times higher than the one strength of B001. The flexural strength of SWD is about three times the Flexure strength of B001, 63MPa, as can be seen in Table 5.4.1. This means that if a decking floor was to be built with polymer decking material, the spam between supports would have to be shorter, corresponding to the need of extra support members, a factor that might increase overall costs.

Thermal Conductivity

The knowledge of the thermal properties of a material is essential for design value specifications for new buildings. All the specimens tested presented a fairly low thermal conductance. Although not calculated with a sufficient number of samples for a correspondents real value result, the overall findings show indication that the conductivity of the material is intrinsically related to the increase of the temperature. From these experimental results it can be stated that the denser the material, the higher the conductivity, as can be observed from the results of the polymer specimens. The results show that the thermal conductivity of the polymer specimens are within the standard conductivity values for polymers specimens, but the wood specimens' conductivity values are below standard values.

Freeze-thaw

The results obtained from this experiment show some variation in weight loss/gain due to repeated freezing and thawing cycles. The results from the dry test showed that after 28 days of freeze-thaw cycles, wet and dry specimens used for the dry test did not show any visual damages or cracks. Aside a small weight loss on wet samples there was no change in width, length or thickness of these specimens, although there was a small percentage of weight loss in all wet specimens. Contrariwise, dry wooden specimens (SWD and HWD) acquired moisture and gained a small percentage of weight, while polymer specimens did not show any change or variation. Specimens used on the wet freezing and thawing experiment showed wear, creep and changes in weight. After this test it was possible to see visual damages. Due to the presence of water which the wooden specimen's absorbed, expansion in all directions occurred as a result of the change in moisture and temperature. The only significant effect of freeze-thaw on the polymer specimens was the visual formation of frost depositions.

Dimension Stability Analysis

All materials are affected by factors during their life span performance. The knowledge of material behaviour under such circumstances is essential for the determination of the material specifications according to its natural properties. From the experimental observations it was possible to see that all specimens in analysis react somehow to heat, although the material behaviour differs from one another. Polymer specimens showed that at 100˚C the material enters into glass transition and reacts by contracting axially and expanding vertically and transversely. The same specimens at 70˚C show minimal change on their thickness. With regard to wood specimens, results show that the presence of moisture and heat poses significant changes to wood. These changes influence in wood in terms of cracks, fungi attacks, distortions, among other issues. Overall this test shows how susceptible both materials are to external factors, with polymer specimens showing great susceptibility to high temperatures and wood specimens to moisture and heat.

Effects of weathering

Weather affects materials gradually and detrimentally, and seeing that the factors affecting the weathering of materials are usually present, the assessment of the effects of such is essential. After 8 months exposure to weathering, polymer specimens (B001 and B002) did not show any relevant change, however, with regard to TSW samples having doubled in weight, it clearly shows a high rate of water absorption. To analyse the material behaviour under the weathering variations the material was kept on the desiccator cabinet. After 21 days TSW samples showed a reduction in weight due to a reduction in moisture content, however, the samples did not yet recover to the initial weight, seeing that the material still has moisture.

Fixtures and bonding

From the carry out of this assessment it is possible to say that Specific polymer adhesives are needed for the bonding of the polymer specimens. From the combination of results, it is also possible to stat that the polymer with wood is able to endure considerable amounts of manually induced load without any problems.

Folling the results obtained it is possible to say that polymer decking is strong denser material that can be worked similarly to wood, without the requirement for treatment, which can be widely used in building and construction industry due to its characteristics. The material is decay and insect resistance, water repellence, have good UV and weather resistance, low maintenance and uniform dimension. This material has minimal impact on the environment as it eliminate waste from waste streams and incinerators, and at its end of life can still be used for other means like pyrolysis or petrol, enhancing the overall product life.

The material is found to be suitable to various applications (exterior and interior furniture, cladding, fencing, and railing, among others), although as this research shows, variance in quality should be expected. Nevertheless, challenges with regard to fire resistance, heat retention, thermal expansion, stiffness and creep as well as acceptance will determine the applications of the material in building and construction industry.

6.2. CONCLUSIONS

The results obtained suggest that there is a potential for this materials to be accepted and used for a wide range of engineering purposes, enabling a more sustainable building and construction industries. The main objective of this research was to characterise the engineering properties of a polymer based wood substitute material and to understand the overall implications of the material in building and construction industry.

After the introductory chapter with the identification of the problem and the definition of objectives for the carry out of this research, the scope of this work relies on literature review to establish the current thinking and knowledge to provide intellectual context, followed by detailed laboratory work and experimentation, and by the findings of the key engineering properties of the materials tested.

The results have shown that the polymer decking material:

- is denser that wood;
- does not absorbs water, but swells negligibly;
- has lower bearing capacity than wood to withstand compressive load;
- suffers higher deformation under load pressure;
- have lower elastic modulus, becoming overall a weaker material;
- is a stiff and brittle material that does not allow bending or flexibility;
- has and overall low conductance, but higher conductance than wood due to its density;
- is highly affected by extreme temperatures, above 90˚C, when the material starts to get on its glass transition, causing exhibiting contraction;
- experience less variations under freeze-thaw conditions;
- does not suffers from root or fungi attack;
- does not suffers from decay, swelling and cracks under normal temperature variations; and,
- can be moulded and shaped with the same tools used for shape wood.

Considering the outcomes of this research is possible to state that the use of polymer material is an attractive wood-substitute for a more sustainable building and construction industries. The experimental results indicate that the polymer material is suitable as wood-substitute but as limitations concerning the material strength and failure mode.

Due to these limitations the material would not be suitable for applications where strength is required or where the failure of the material would preclude health and safety. Nevertheless, the outcomes of this research demonstrates that this material would be more suitable than wood for outdoor applications such as decking, urban furniture, cladding, and playground structures, among others. The use of the polymer material to substitute wood would be especially striking for applications where a long lasting material would minimise costs and maintenance related to damages arisen from weather exposition, temperature variations, root and fungi attack.

The replacement of wood in such applications would not only minimise the constant demand for new/raw materials but would also allow for a more sustainable and friendly use and conservation of natural resources. Overall, the use of the polymer material would enable for cradle-to-cradle assessments of resource use, having on mind the end of life cycle of the material, minimising waste, which will allow building and construction industries to be more ennobling towards sustainability.

6.3. RECOMMENDATIONS

Although this research work covered a wide range of engineering tests, there are still several engineering properties to be determined. Further work would have to be carried out to specify the optimum mix for industrial production of the polymer material. To mitigate strength problems on the utilisation of the material as it stands, extra supports would be required to sustain raised structures.

Bering in mind the tests and results obtained it is also recommended that:

- Further work should to be carried out to improve the material flexural performance, possible the combination of EPS with some other polymer material.
- It is believed that further work would need to be carried out to determine the material fire resistance.
- Further work should to be carried out to other design shapes, aside decking for the determination of the engineering properties of panels, bricks, etc.
- A wider range of analytical studies, especially with regard to the material microstructure, should be carried out to understand the crystallinity of the material.
- Acoustic studies should also be carried out, as this material is intended to be used for building and construction.
- A market survey and material acceptance study would be also needed to investigate not only the prices but also the public acceptance of the material.
- A thorough environmental analysis, specific to the material should be carried out to analyse the material from cradle-to-cradle and cradle-to-grave.

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APPENDIX

Appendix A – Samples Dimensions

Number	Height (mm) h	Width (mm) w	Length (mm) l	Neg Height (mm) h	Neg Width (mm) w	Neg Length (mm) l
8	25.02	27.61	22.89	3	12	22.89
9	24.68	25.44	23.44	3	12	23.44
10	25.13	25.54	24.01	3	12	24.01
11	24.82	25.43	24.10	3	12	24.10
12	24.90	27.63	23.77	3	12	23.77
13	24.70	25.52	23.91	3	12	23.91
17	24.34	26.24	23.49	3	12	23.49
18	25.01	25.61	24.00	3	12	24.00
19	25.19	25.72	24.07	3	12	24.07
20	24.68	25.75	23.52	3	12	23.52
21	25.19	26.35	23.45	3	12	23.45
22	25.27	25.63	23.46	3	12	23.46
23	25.01	25.70	24.13	3	12	24.13
24	24.95	25.78	23.48	3	12	23.48
25	25.17	26.23	23.36	3	12	23.36
26	24.90	25.65	24.16	3	12	24.16
27	24.16	25.69	23.51	3	12	23.51
28	25.03	25.71	23.47	3	12	23.47
29	24.90	25.69	24.11	3	12	24.11
30	25.02	25.65	23.44	3	12	23.44
31	25.03	26.58	23.38	3	12	23.38
32	25.15	26.35	24.22	3	12	24.22
33	25.06	25.73	23.32	3	12	23.32
34	25.13	26.30	23.40	3	12	23.40
35	24.48	14.01	24.17	3	12	24.17
36	23.78	25.71	24.20	3	12	24.20
37	25.21	26.75	24.20	3	12	24.20
38	25.13	25.65	24.14	3	12	24.14
39	24.48	25.66	23.51	3	12	23.51
40	24.89	25.65	24.13	3	12	24.13
41	24.98	26.41	23.51	3	12	23.51
42	24.84	14.61	24.12	3	12	24.12
43	7.85	25.67	24.10	3	12	24.10
44	24.98	25.26	23.45	3	12	23.45
45	13.62	19.79	24.14	3	12	24.14
46	24.98	25.65	23.46	3	12	23.46
47	24.94	19.80	24.12	3	12	24.12
48	25.25	25.68	24.16	3	12	24.16
49	25.14	25.70	23.36	3	12	23.36
50	25.25	25.54	24.10	3	12	24.10
51	25.00	25.72	23.50	3	12	23.50

Cubes B001

Number	Height (mm) h	Width (mm) w	Length (mm) l	Neg Height (mm)	Neg Width (mm) w	Neg Length (mm) l
1	22.54	26.56	27.21	3	12	27.21
2	22.45	26.73	26.96	3	12	26.96
3	24.03	26.69	26.98	3	12	26.98
4	22.51	26.72	26.88	3	12	26.88
5	22.78	26.23	27.15	3	12	27.15
6	22.50	27.04	26.34	3	12	26.34
7	24.08	26.70	26.87	3	12	26.87
8	24.00	26.37	27.14	3	12	27.14
9	24.03	26.82	26.48	3	12	26.48
10	22.75	27.02	26.80	3	12	26.80
11	22.80	26.90	27.33	3	12	27.33
12	24.00	26.48	27.21	3	12	27.21
13	22.80	26.72	27.19	3	12	27.19
14	22.77	27.18	26.54	3	12	26.54
15	24.04	26.07	27.06	3	12	27.06
16	22.80	26.81	27.26	3	12	27.26
17	23.93	26.86	26.79	3	12	26.79
18	24.09	27.34	25.10	3	12	25.10
19	24.05	27.79	25.18	3	12	25.18
20	24.06	27.54	24.98	3	12	24.98
21	24.07	27.56	25.07	3	12	25.07
22	22.84	25.96	25.00	3	12	25.00
23	24.07	27.95	25.29	3	12	25.29
24	24.07	27.62	24.90	3	12	24.90
25	24.10	27.51	25.19	3	12	25.19
26	24.05	27.69	24.73	3	12	24.73
27	22.79	26.07	25.05	3	12	25.05
28	22.82	25.88	25.13	3	12	25.13
29	23.05	26.16	24.42	3	12	24.42

Cubes B002

Number	Height (mm) h	Width (mm) w	Length (mm) l	Neg Height (mm)	Neg Width (mm) w	Neg Length (mm) l
1	27.17	27.05	24.15	3	12	24.15
2	26.92	27.14	23.34	3	12	23.34
3	26.92	26.30	24.12	3	12	24.12
4	27.07	26.32	22.87	3	12	22.87
5	26.44	26.75	23.28	3	12	23.28
6	26.73	27.02	23.06	3	12	23.06
7	26.93	26.79	23.11	3	12	23.11

8	27.18	26.72	23.07	3	12	23.07
9	26.96	25.39	24.00	3	12	24.00
10	27.25	26.34	24.37	3	12	24.37
11	26.96	24.99	23.98	3	12	23.98
12	27.22	26.33	22.76	3	12	22.76
13	27.20	26.91	23.29	3	12	23.29
14	27.22	26.63	24.36	3	12	24.36
15	27.58	26.45	22.95	3	12	22.95
16	26.78	27.06	24.28	3	12	24.28
17	27.03	26.22	22.67	3	12	22.67
18	27.27	26.60	23.10	3	12	23.10
19	27.03	24.60	23.99	3	12	23.99
20	26.81	26.05	24.31	3	12	24.31
21	27.05	26.33	24.40	3	12	24.40
22	26.97	26.57	22.71	3	12	22.71
23	27.24	26.32	22.93	3	12	22.93
24	27.39	26.44	24.36	3	12	24.36
25	25.62	29.51	22.70	3	12	22.70
26	25.55	29.68	22.73	3	12	22.73
27	25.88	29.16	22.78	3	12	22.78
28	25.81	24.80	24.04	3	12	24.04
29	25.66	24.89	23.98	3	12	23.98
30	25.49	25.36	22.70	3	12	22.70

Cubes B003

Number	**Height (mm) h**	**Width (mm) w**	**Length (mm) l**	**Neg Height (mm)**	**Neg Width (mm) w**	**Neg Length (mm) l**
1	27.11	31.77	26.07	4.03	5.79	26.07
2	26.94	31.39	26.06	4.03	9.58	26.06
3	27.08	32.04	26.20	4.03	5.79	26.20
4	27.21	30.75	25.94	4.03	5.79	25.94
5	27.09	31.07	25.95	4.03	5.79	25.95
6	27.13	32.21	26.13	4.03	5.79	26.13
7	27.08	31.04	25.93	4.03	5.79	25.93
8	27.00	30.83	25.84	4.03	5.79	25.84
9	27.19	31.81	26.13	4.03	5.79	26.13
10	27.15	31.80	26.12	4.03	5.79	26.12
11	27.17	31.85	26.08	4.03	5.79	26.08
12	27.26	30.82	25.87	4.03	5.79	25.87
13	27.19	29.98	26.12	4.03	5.79	26.12
14	27.27	30.80	25.93	4.03	5.79	25.93
15	27.29	29.76	26.11	4.03	5.79	26.11
16	27.19	30.36	26.11	4.03	5.79	26.11
17	27.06	31.17	25.89	4.03	5.79	25.89

18	27.04	31.13	25.95	4.03	5.79	25.95
19	27.08	32.03	26.04	4.03	5.79	26.04
20	27.23	30.74	26.18	4.03	5.79	26.18
21	26.94	31.24	26.93	4.03	5.79	26.93
22	27.05	31.09	25.82	4.03	5.79	25.82
23	27.29	31.29	25.96	4.03	9.58	25.96
24	26.85	31.31	26.11	4.03	9.58	26.11
25	27.36	31.79	25.94	4.03	9.58	25.94
26	26.82	31.09	25.81	4.03	9.58	25.81
27	26.80	31.47	25.86	4.03	9.58	25.86
28	26.83	31.34	25.91	4.03	9.58	25.91
29	26.69	30.16	25.99	4.03	9.58	25.99
30	27.31	31.36	25.89	4.03	9.58	25.89
31	27.42	31.87	25.66	4.03	9.58	25.66
32	27.10	30.87	26.07	4.03	9.58	26.07
33	26.71	30.47	25.95	4.03	9.58	25.95
34	27.28	31.38	25.88	4.03	9.58	25.88
35	26.81	31.12	25.75	4.03	9.58	25.75
36	27.31	32.17	25.65	4.03	9.58	25.65
37	27.27	32.00	25.82	4.03	9.58	25.82
38	27.10	30.76	26.16	4.03	9.58	26.16
39	27.32	31.39	25.93	4.03	9.58	25.93
40	27.14	30.86	26.19	4.03	9.58	26.19
41	27.10	30.94	26.08	4.03	9.58	26.08

Cubes SWD

Number	**Height (mm) h**	**Width (mm) w**	**Length (mm) l**	**Neg Height (mm)**	**Neg Width (mm) w**	**Neg Length (mm) l**
1	0.00	0.00	0.00	2.51	3.7	0.00
2	21.62	29.41	25.87	2.51	3.7	25.87
3	21.56	28.41	25.79	2.51	3.7	25.79
4	21.54	28.36	25.41	2.51	3.7	25.41
5	21.61	28.40	25.77	2.51	3.7	25.77
6	21.47	28.30	25.65	2.51	3.7	25.65
7	21.45	29.18	25.79	2.51	3.7	25.79
8	21.51	28.38	25.65	2.51	3.7	25.65
9	21.46	28.43	25.78	2.51	3.7	25.78
10	21.56	27.81	25.58	2.51	3.7	25.58
11	21.48	28.39	25.63	2.51	3.7	25.63
12	21.43	28.25	25.80	2.51	3.7	25.80
13	21.57	27.96	25.62	2.51	3.7	25.62
14	21.56	29.27	25.63	2.51	3.7	25.63
15	21.45	28.41	25.69	2.51	3.7	25.69
16	21.61	28.18	25.79	2.51	3.7	25.79

17	21.48	28.34	25.82	2.51	3.7	25.82
18	21.60	29.39	25.83	2.51	3.7	25.83
19	21.60	28.49	25.80	2.51	3.7	25.80
20	21.58	27.48	25.78	2.51	3.7	25.78
21	21.70	28.39	25.62	2.51	3.7	25.62
22	21.43	29.19	25.65	2.51	3.7	25.65
23	21.57	28.44	25.81	2.51	3.7	25.81
24	21.46	29.19	25.77	2.51	3.7	25.77
25	21.58	27.79	25.80	2.51	3.7	25.80
26	21.47	27.54	25.80	2.51	3.7	25.80
27	21.41	28.23	25.78	2.51	3.7	25.78

Cubes HWD

Polymer Blocks

Number	Height (mm) h	Width (mm) w	Length (mm) l	Neg Height (mm)	Neg Width (mm) w	Neg Length (mm) l	Weigh (g)
1	24.68	123.87	150.01	12.00	48.00	150.01	373.45
2	24.74	123.80	149.84	12.00	48.00	149.84	374.41
3	24.73	123.79	149.80	12.00	48.00	149.80	373.84
4	24.72	123.86	148.24	12.00	48.00	148.24	349.10
5	24.73	123.85	149.77	12.00	48.00	149.77	357.96
6	24.75	124.08	150.11	12.00	48.00	150.11	368.03
7	24.71	123.82	149.92	12.00	48.00	149.92	345.00
8	24.73	123.78	149.58	12.00	48.00	149.58	346.80
9	24.75	123.96	149.91	12.00	48.00	149.91	371.63
10	24.77	123.87	149.53	12.00	48.00	149.53	294.17
11	24.76	123.89	150.02	12.00	48.00	150.02	293.38
12	24.77	123.85	149.77	12.00	48.00	149.77	296.53
13	24.77	123.90	149.55	12.00	48.00	149.55	286.20
14	24.79	123.80	149.86	12.00	48.00	149.86	295.69
15	24.78	123.90	149.67	12.00	48.00	149.67	297.20
16	24.70	124.09	149.62	12.00	48.00	149.62	318.44
17	24.34	123.79	149.58	12.00	48.00	149.58	318.10
18	24.44	123.86	149.72	12.00	48.00	149.72	327.29
19	24.82	123.71	149.70	12.00	48.00	149.70	386.23
20	24.74	123.77	149.62	12.00	48.00	149.62	288.54
21	24.58	123.69	149.46	12.00	48.00	149.46	317.42
22	24.76	123.74	149.67	12.00	48.00	149.67	385.46
23	24.77	123.74	149.57	12.00	48.00	149.57	386.11
24	24.75	123.74	149.51	12.00	48.00	149.51	385.92
25	24.77	123.83	150.08	12.00	48.00	150.08	290.35
26	24.75	123.87	149.82	12.00	48.00	149.82	287.47
27	24.75	123.80	149.05	12.00	48.00	149.05	287.73
28	24.76	123.74	149.40	12.00	48.00	149.40	318.48
29	24.71	123.79	149.91	12.00	48.00	149.91	318.92

30	24.66	123.76	149.87	12.00	48.00	149.87	318.98
43	24.65	123.83	100.95	12.00	48.00	100.95	247.09
44	24.63	123.74	101.13	12.00	48.00	101.13	248.45
45	24.62	123.77	100.92	12.00	48.00	100.92	248.76
46	24.63	123.68	101.02	12.00	48.00	101.02	250.04
47	24.52	124.02	100.82	12.00	48.00	100.82	195.61
48	24.78	123.78	100.39	12.00	48.00	100.39	196.29
49	24.77	123.87	100.46	12.00	48.00	100.46	195.63
50	24.79	123.73	100.58	12.00	48.00	100.58	197.17
51	24.34	123.70	100.74	12.00	48.00	100.74	216.48
52	24.70	123.72	100.49	12.00	48.00	100.49	215.17
53	24.70	123.78	100.62	12.00	48.00	100.62	216.30
54	24.71	123.80	100.64	12.00	48.00	100.64	216.22

B001
B002
B003

HWD Block

Number	Height (mm) h	Width (mm) w	Length (mm) l	Neg Height (mm)	Neg Width (mm) w	Neg Length (mm) l	Weigh (g)
1	21.67	145.27	100.46	2.51	37	100.46	140.67
2	21.58	145.40	149.31	2.51	37	149.31	207.57
3	21.78	145.44	149.57	2.51	37	149.57	213.77
4	21.63	145.44	149.29	2.51	37	149.29	211.34
5	21.55	145.37	149.50	2.51	37	149.50	212.76
6	21.58	145.39	149.60	2.51	37	149.60	217.12
7	21.60	145.42	149.63	2.51	37	149.63	217.50
8	21.57	145.39	149.52	2.51	37	149.52	210.71
9	21.63	145.39	100.50	2.51	37	149.40	139.51
10	21.60	145.33	100.58	2.51	37	149.53	142.37
11	21.58	145.38	100.58	2.51	37	149.63	140.87
12	21.59	145.33	149.62	2.51	37	149.62	209.31
13	21.56	145.12	149.48	2.51	37	149.48	204.20
14	21.57	145.31	149.65	2.51	37	149.65	213.73

SWD Block

Number	Height (mm) h	Width (mm) w	Length (mm) l	Neg Height (mm)	Neg Width (mm) w	Neg Length (mm) l	Weigh (g)
1	26.95	140.78	149.46	3.85	44.29	149.46	247.91
2	26.90	141.01	149.58	3.85	44.29	149.58	239.58
3	26.82	140.98	149.38	3.85	44.29	149.38	241.61

4	26.95	140.78	149.74	3.85	44.29	149.74	240.36
5	27.02	141.01	149.82	3.85	44.29	149.82	206.17
6	26.84	140.94	149.47	3.85	44.29	149.47	219.37
7	26.92	141.25	149.45	3.85	44.29	149.45	207.68
8	27.01	140.74	149.82	3.85	44.29	149.82	239.15
9	26.99	140.70	149.53	3.85	44.29	149.53	241.23
10	26.89	141.00	149.73	3.85	44.29	149.73	251.27
11	26.91	140.93	149.83	3.85	44.29	149.83	249.67
12	26.88	140.70	150.01	3.85	44.29	150.01	246.30
13	27.00	140.80	149.73	3.85	44.29	149.73	258.18
14	27.07	140.88	149.79	3.85	44.29	149.79	249.37
15	26.97	140.60	100.81	3.85	44.29	100.81	162.46
16	26.88	140.63	100.65	3.85	44.29	100.65	155.50
17	26.78	140.65	100.83	3.85	44.29	100.83	154.35
18	26.64	140.77	100.63	3.85	44.29	100.63	160.06
19	26.83	140.81	100.44	3.85	44.29	100.44	167.75

TSW Block

Number	Height (mm) h	Width (mm) w	Length (mm) l	Weigh (g)
1	48.08	100.14	150.28	304.23
2	47.88	99.90	150.37	278.36
3	48.16	99.92	150.26	284.22
4	42.29	90.72	149.80	242.93
5	42.28	91.58	149.85	247.58
6	41.74	91.71	150.04	248.72
7	41.73	92.42	149.94	244.64
8	41.65	92.11	149.94	246.35
9	42.32	91.64	149.80	275.11

Appendix B – Density Data

B001 Blocks

		1	2	3 (1-2)	4	5	6 (4-5)	7	8 (3-6)	9 (7/8)	10 9*1000
	Number	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	Material Density (g/cm3)	Material Density (kg/m3)
Immediate	**1**	1941	1228	713	1563.08	1364	199.08	373.45	513.92	0.727	727
	2	1942	1289	653	1563.08	1364	199.08	374.41	453.92	0.825	825
	3	1941	1290	651	1563.08	1364	199.08	373.84	451.92	0.827	827
										Average	**793**
1 Day	**1**	1967	1295	672	1563.08	1364	199.08	373.45	472.92	0.790	790
	2	1943	1291	652	1563.08	1364	199.08	374.41	452.92	0.827	827
	3	1941	1291	650	1563.08	1364	199.08	373.84	450.92	0.829	829
										Average	**815**
2 Days	**1**	1942	1294	648	1563.08	1364	199.08	373.45	448.92	0.832	832
	2	1944	1302	642	1563.08	1364	199.08	374.41	442.92	0.845	845
	3	1942	1296	646	1563.08	1364	199.08	373.84	446.92	0.836	836
										Average	**838**
3 Days	**1**	1944	1300	644	1563.08	1364	199.08	373.45	444.92	0.839	839
	2	1944	1295	649	1563.08	1364	199.08	374.41	449.92	0.832	832
	3	1942	1292	650	1563.08	1364	199.08	373.84	450.92	0.829	829
										Average	**834**
4 Days	**1**	1941	1297	644	1563.08	1364	199.08	373.45	444.92	0.839	839
	2	1942	1293	649	1563.08	1364	199.08	374.41	449.92	0.832	832
	3	1941	1294	647	1563.08	1364	199.08	373.84	447.92	0.835	835

										Average	**835**
7 Days	**1**	1944	1300	644	1563.08	1364	199.08	373.45	444.92	0.839	839
	2	1943	1295	648	1563.08	1364	199.08	374.41	448.92	0.834	834
	3	1943	1296	647	1563.08	1364	199.08	373.84	447.92	0.835	835
										Average	**836**
8 Days	**1**	1944	1294	650	1563.08	1364	199.08	373.45	450.92	0.828	828
	2	1944	1293	651	1563.08	1364	199.08	374.41	451.92	0.828	828
	3	1943	1295	648	1563.08	1364	199.08	373.84	448.92	0.833	833
										Average	**830**
9 Days	**1**	1943	1295	648	1563.08	1364	199.08	373.45	448.92	0.832	832
	2	1943	1295	648	1563.08	1364	199.08	374.41	448.92	0.834	834
	3	1944	1296	648	1563.08	1364	199.08	373.84	448.92	0.833	833
										Average	**833**
10 Days	**1**	1943	1295	648	1563.08	1364	199.08	373.45	448.92	0.832	832
	2	1943	1296	647	1563.08	1364	199.08	374.41	447.92	0.836	836
	3	1943	1293	650	1563.08	1364	199.08	373.84	450.92	0.829	829
										Average	**832**
11 Days	**1**	1942	1293	649	1563.08	1364	199.08	373.45	449.92	0.830	830
	2	1942	1293	649	1563.08	1364	199.08	374.41	449.92	0.832	832
	3	1942	1294	648	1563.08	1364	199.08	373.84	448.92	0.833	833
										Average	**832**
14 Days	**1**	1943	1295	648	1563.08	1364	199.08	373.45	448.92	0.832	832
	2	1943	1297	646	1563.08	1364	199.08	374.41	446.92	0.838	838
	3	1942	1294	648	1563.08	1364	199.08	373.84	448.92	0.833	833
										Average	**834**
15 Days	**1**	1942	1293	649	1563.08	1364	199.08	373.45	449.92	0.830	830
	2	1943	1293	650	1563.08	1364	199.08	374.41	450.92	0.830	830

	3	1942	1297	645	1563.08	1364	199.08	373.84	445.92	0.838	838
										Average	**833**
16 Days	**1**	1944	1297	647	1563.08	1364	199.08	373.45	447.92	0.834	834
	2	1943	1293	650	1563.08	1364	199.08	374.41	450.92	0.830	830
	3	1943	1297	646	1563.08	1364	199.08	373.84	446.92	0.836	836
										Average	**834**
17 Days	**1**	1942	1293	649	1563.08	1364	199.08	373.45	449.92	0.830	830
	2	1943	1294	649	1563.08	1364	199.08	374.41	449.92	0.832	832
	3	1944	1293	651	1563.08	1364	199.08	373.84	451.92	0.827	827
										Average	**830**
18 Days	**1**	1943	1292	651	1563.08	1364	199.08	373.45	451.92	0.826	826
	2	1944	1293	651	1563.08	1364	199.08	374.41	451.92	0.828	828
	3	1943	1298	645	1563.08	1364	199.08	373.84	445.92	0.838	838
										Average	**831**
53 Days	**1**	1974	1300	674	1563.08	1364	199.08	373.45	474.92	0.786	786
	2	1945	1300	645	1563.08	1364	199.08	374.41	445.92	0.840	840
	3	1945	1285	660	1563.08	1364	199.08	373.84	460.92	0.811	811
										Average	**812**
74 Days	**1**	1944	1308	636	1563.08	1364	199.08	373.45	436.92	0.855	855
	2	1944	1294	650	1563.08	1364	199.08	374.41	450.92	0.830	830
	3	1943	1307	636	1563.08	1364	199.08	373.84	436.92	0.856	856
										Average	**847**
91 Days	**1**	1943	1301	642	1563.08	1364	199.08	373.45	442.92	0.843	843
	2	1944	1298	646	1563.08	1364	199.08	374.41	446.92	0.838	838
	3	1943	1296	647	1563.08	1364	199.08	373.84	447.92	0.835	835
										Average	**839**

108 Days	**1**	1944	1295	649	1563.08	1364	199.08	373.45	449.92	0.830	830
	2	1945	1294	651	1563.08	1364	199.08	374.41	451.92	0.828	828
	3	1946	1297	649	1563.08	1364	199.08	373.84	449.92	0.831	831
										Average	**830**

B001 Blocks (90)

		1	2	3	4	5	6	7	8	9	10
				(1-2)			(4-5)		(3-6)	(7/8)	9*1000
	Number	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	Material Density (g/cm3)	Material Density (kg/m3)
Immediate	**22**	1954	1298	656	1563.08	1364	199.08	385.46	456.92	0.844	844
	23	1953	1302	651	1563.08	1364	199.08	386.11	451.92	0.854	854
	24	1953	1298	655	1563.08	1364	199.08	385.92	455.92	0.846	846
										Average	**848**
7 days	**22**	1954	1300	654	1563.08	1364	199.08	385.46	454.92	0.847	847
	23	1954	1304	650	1563.08	1364	199.08	386.11	450.92	0.856	856
	24	1954	1305	649	1563.08	1364	199.08	385.92	449.92	0.858	858
										Average	**854**
14 days	**22**	1934	1285	649	1563.08	1364	199.08	385.46	449.92	0.857	857
	23	1935	1285	650	1563.08	1364	199.08	386.11	450.92	0.856	856
	24	1935	1285	650	1563.08	1364	199.08	385.92	450.92	0.856	856
										Average	**856**
28 days	**22**	1935	1285	650	1563.08	1364	199.08	385.46	450.92	0.855	855
	23	1936	1285	651	1563.08	1364	199.08	386.11	451.92	0.854	854

	24	1936	1281	655	1563.08	1364	199.08	385.92	455.92	0.846	846
										Average	**852**
56 days	**22**	1938	1286	652	1563.08	1364	199.08	385.46	452.92	0.851	851
	23	1937	1289	648	1563.08	1364	199.08	386.11	448.92	0.860	860
	24	1938	1287	651	1563.08	1364	199.08	385.92	451.92	0.854	854
										Average	**855**
90 days	**22**	1935	1281	654	1563.08	1364	199.08	385.46	454.92	0.847	847
	23	1936	1282	654	1563.08	1364	199.08	386.11	454.92	0.849	849
	24	1936	1285	651	1563.08	1364	199.08	385.92	451.92	0.854	854
										Average	**850**

B002 Blocks (90)		1	2	3	4	5	6	7	8	9	10
				(1-2)			(4-5)		(3-6)	(7/8)	9*1000
	Number	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	Material Density (g/cm3)	Material Density (kg/m3)
Immediate	**25**	1856	1229	627	1563.08	1364	199.08	290.35	427.92	0.679	679
	26	1854	1232	622	1563.08	1364	199.08	287.47	422.92	0.680	680
	27	1855	1231	624	1563.08	1364	199.08	287.73	424.92	0.677	677
										Average	**678**
7 days	**25**	1859	1238	621	1563.08	1364	199.08	290.35	421.92	0.688	688
	26	1855	1236	619	1563.08	1364	199.08	287.47	419.92	0.685	685
	27	1856	1238	618	1563.08	1364	199.08	287.73	418.92	0.687	687
										Average	**687**

14 days	**25**	1840	1222	618	1563.08	1364	199.08	290.35	418.92	0.693	693
	26	1837	1217	620	1563.08	1364	199.08	287.47	420.92	0.683	683
	27	1836	1221	615	1563.08	1364	199.08	287.73	415.92	0.692	692
										Average	**689**
28 days	**25**	1840	1216	624	1563.08	1364	199.08	290.35	424.92	0.683	683
	26	1838	1219	619	1563.08	1364	199.08	287.47	419.92	0.685	685
	27	1838	1220	618	1563.08	1364	199.08	287.73	418.92	0.687	687
										Average	**685**
56 days	**25**	1842	1217	625	1563.08	1364	199.08	290.35	425.92	0.682	682
	26	1839	1221	618	1563.08	1364	199.08	287.47	418.92	0.686	686
	27	1838	1223	615	1563.08	1364	199.08	287.73	415.92	0.692	692
										Average	**687**
90 days	**25**	1840	1218	622	1563.08	1364	199.08	290.35	422.92	0.687	687
	26	1838	1217	621	1563.08	1364	199.08	287.47	421.92	0.681	681
	27	1838	1223	615	1563.08	1364	199.08	287.73	415.92	0.692	692
										Average	**687**

B003 Blocks (90)		1	2	3	4	5	6	7	8	9	10
				(1-2)			(4-5)		(3-6)	(7/8)	9*1000
										Material Density	
Immediate	**Number**	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	(g/cm3)	(kg/m3)
	28	1886	1272	614	1563.08	1364	199.08	318.48	414.92	0.768	768
	29	1885	1270	615	1563.08	1364	199.08	318.92	415.92	0.767	767

	30	1886	1265	621	1563.08	1364	199.08	318.98	421.92	0.756	756
										Average	**763**
7 days	**28**	1887	1274	613	1563.08	1364	199.08	318.48	413.92	0.769	769
	29	1888	1270	618	1563.08	1364	199.08	318.92	418.92	0.761	761
	30	1887	1273	614	1563.08	1364	199.08	318.98	414.92	0.769	769
										Average	**766**
14 days	**28**	1869	1262	607	1563.08	1364	199.08	318.48	407.92	0.781	781
	29	1869	1252	617	1563.08	1364	199.08	318.92	417.92	0.763	763
	30	1868	1256	612	1563.08	1364	199.08	318.98	412.92	0.772	772
										Average	**772**
28 days	**28**	1869	1263	606	1563.08	1364	199.08	318.48	406.92	0.783	783
	29	1869	1255	614	1563.08	1364	199.08	318.92	414.92	0.769	769
	30	1869	1251	618	1563.08	1364	199.08	318.98	418.92	0.761	761
										Average	**771**
56 days	**28**	1871	1255	616	1563.08	1364	199.08	318.48	416.92	0.764	764
	29	1871	1255	616	1563.08	1364	199.08	318.92	416.92	0.765	765
	30	1871	1256	615	1563.08	1364	199.08	318.98	415.92	0.767	767
										Average	**765**
90 days	**28**	1869	1265	604	1563.08	1364	199.08	318.48	404.92	0.787	787
	29	1869	1255	614	1563.08	1364	199.08	318.92	414.92	0.769	769
	30	1869	1254	615	1563.08	1364	199.08	318.98	415.92	0.767	767
										Average	**774**

TSW Blocks		1	2	3	4	5	6	7	8	9	10
				(1-2)			(4-5)		(3-6)	(7/8)	9*1000
	Number	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	Material Density (g/cm3)	Material Density (kg/m3)
Immediate	**1**	1880	957	923	1563.08	1364	199.08	304.23	723.92	0.420	420
	2	1854	936	918	1563.08	1364	199.08	278.36	718.92	0.387	387
	3	1858	934	924	1563.08	1364	199.08	284.22	724.92	0.392	392
										Average	**400**
1 Day	**1**	1924	948	976	1563.08	1364	199.08	304.23	776.92	0.392	392
	2	1896	957	939	1563.08	1364	199.08	278.36	739.92	0.376	376
	3	1900	958	942	1563.08	1364	199.08	284.22	742.92	0.383	383
										Average	**383**
2 Days	**1**	1941	996	945	1563.08	1364	199.08	304.23	745.92	0.408	408
	2	1910	968	942	1563.08	1364	199.08	278.36	742.92	0.375	375
	3	1910	968	942	1563.08	1364	199.08	284.22	742.92	0.383	383
										Average	**388**
3 Days	**1**	1951	1003	948	1563.08	1364	199.08	304.23	748.92	0.406	406
	2	1919	974	945	1563.08	1364	199.08	278.36	745.92	0.373	373
	3	1924	974	950	1563.08	1364	199.08	284.22	750.92	0.378	378
										Average	**386**
4 Days	**1**	1958	1007	951	1563.08	1364	199.08	304.23	751.92	0.405	405
	2	1927	979	948	1563.08	1364	199.08	278.36	748.92	0.372	372
	3	1930	978	952	1563.08	1364	199.08	284.22	752.92	0.377	377
										Average	**385**
7 Days	**1**	1989	1032	957	1563.08	1364	199.08	304.23	757.92	0.401	401
	2	1956	1003	953	1563.08	1364	199.08	278.36	753.92	0.369	369

	3	1961	1003	958	1563.08	1364	199.08	284.22	758.92	0.375	375
										Average	**382**
8 Days	**1**	2000	1042	958	1563.08	1364	199.08	304.23	758.92	0.401	401
	2	1968	1012	956	1563.08	1364	199.08	278.36	756.92	0.368	368
	3	1972	1011	961	1563.08	1364	199.08	284.22	761.92	0.373	373
										Average	**381**
9 Days	**1**	2001	1051	950	1563.08	1364	199.08	304.23	750.92	0.405	405
	2	1976	1021	955	1563.08	1364	199.08	278.36	755.92	0.368	368
	3	1981	1021	960	1563.08	1364	199.08	284.22	760.92	0.374	374
										Average	**382**
10 Days	**1**	2016	1057	959	1563.08	1364	199.08	304.23	759.92	0.400	400
	2	1984	1028	956	1563.08	1364	199.08	278.36	756.92	0.368	368
	3	1987	1028	959	1563.08	1364	199.08	284.22	759.92	0.374	374
										Average	**381**
11 Days	**1**	2023	1065	958	1563.08	1364	199.08	304.23	758.92	0.401	401
	2	1991	1036	955	1563.08	1364	199.08	278.36	755.92	0.368	368
	3	1995	1035	960	1563.08	1364	199.08	284.22	760.92	0.374	374
										Average	**381**
14 Days	**1**	2039	1082	957	1563.08	1364	199.08	304.23	757.92	0.401	401
	2	2009	1053	956	1563.08	1364	199.08	278.36	756.92	0.368	368
	3	2013	1052	961	1563.08	1364	199.08	284.22	761.92	0.373	373
										Average	**381**
15 Days	**1**	2045	1086	959	1563.08	1364	199.08	304.23	759.92	0.400	400
	2	2015	1058	957	1563.08	1364	199.08	278.36	757.92	0.367	367
	3	2017	1057	960	1563.08	1364	199.08	284.22	760.92	0.374	374
										Average	**380**
16	**1**	2049	1090	959	1563.08	1364	199.08	304.23	759.92	0.400	400

Days	2	2018	1062	956	1563.08	1364	199.08	278.36	756.92	0.368	368
	3	2020	1061	959	1563.08	1364	199.08	284.22	759.92	0.374	374
										Average	**381**
17 Days	1	2050	1093	957	1563.08	1364	199.08	304.23	757.92	0.401	401
	2	2021	1065	956	1563.08	1364	199.08	278.36	756.92	0.368	368
	3	2023	1063	960	1563.08	1364	199.08	284.22	760.92	0.374	374
										Average	**381**
18 Days	1	2054	1096	958	1563.08	1364	199.08	304.23	758.92	0.401	401
	2	2025	1069	956	1563.08	1364	199.08	278.36	756.92	0.368	368
	3	2028	1067	961	1563.08	1364	199.08	284.22	761.92	0.373	373
										Average	**381**
53 Days	1	2106	1145	961	1563.08	1364	199.08	304.23	761.92	0.399	399
	2	2080	1121	959	1563.08	1364	199.08	278.36	759.92	0.366	366
	3	2085	1120	965	1563.08	1364	199.08	284.22	765.92	0.371	371
										Average	**379**
74 Days	1	2128	1166	962	1563.08	1364	199.08	304.23	762.92	0.399	399
	2	2100	1141	959	1563.08	1364	199.08	278.36	759.92	0.366	366
	3	2104	1140	964	1563.08	1364	199.08	284.22	764.92	0.372	372
										Average	**379**
91 Days	1	2220	1175	1045	1563.08	1364	199.08	304.23	845.92	0.360	360
	2	2200	1149	1051	1563.08	1364	199.08	278.36	851.92	0.327	327
	3	2190	1149	1041	1563.08	1364	199.08	284.22	841.92	0.338	338
										Average	**341**
108 Days	1	2151	1188	963	1563.08	1364	199.08	304.23	763.92	0.398	398
	2	2122	1162	960	1563.08	1364	199.08	278.36	760.92	0.366	366
	3	2128	1168	960	1563.08	1364	199.08	284.22	760.92	0.374	374
										Average	**379**

Hardwood Blocks		1	2	3 (1-2)	4	5	6 (4-5)	7	8 (3-6)	9 (7/8)	10 9*1000
	Number	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	Material Density (g/cm3)	Material Density (kg/m3)
Immediate	**2**	1754	1092	662	1563.08	1364	199.08	207.57	462.92	0.448	448
	3	1761	1098	663	1563.08	1364	199.08	213.77	463.92	0.461	461
	4	1758	1096	662	1563.08	1364	199.08	211.34	462.92	0.457	457
										Average	**455**
7 days	**2**	1828	1138	690	1563.08	1364	199.08	207.57	490.92	0.423	423
	3	1831	1148	683	1563.08	1364	199.08	213.77	483.92	0.442	442
	4	1830	1146	684	1563.08	1364	199.08	211.34	484.92	0.436	436
										Average	**433**
14 days	**2**	1877	1180	697	1563.08	1364	199.08	207.57	497.92	0.417	417
	3	1882	1188	694	1563.08	1364	199.08	213.77	494.92	0.432	432
	4	1883	1188	695	1563.08	1364	199.08	211.34	495.92	0.426	426
										Average	**425**
28 days	**2**	1906	1250	656	1563.08	1364	199.08	207.57	456.92	0.454	454
	3	1909	1274	635	1563.08	1364	199.08	213.77	435.92	0.490	490
	4	1913	1259	654	1563.08	1364	199.08	211.34	454.92	0.465	465
										Average	**470**
90 days	**2**	1928	1233	695	1563.08	1364	199.08	207.57	495.92	0.419	419
	3	1932	1241	691	1563.08	1364	199.08	213.77	491.92	0.435	435
	4	1932	1240	692	1563.08	1364	199.08	211.34	492.92	0.429	429
										Average	**427**

Softwood Blocks		1	2	3	4	5	6	7	8	9	10
				(1-2)			(4-5)		(3-6)	(7/8)	9*1000
	Number	Combined wt in air (g)	Combined wt in Water (g)	Combined Volume (cm3)	Steel wt scale(g)	Steel wt in water (g)	Volume of Steel (cm3)	Material wt (g)	Material Volume (cm3)	Material Density (g/cm3)	Material Density (kg/m3)
Immediate	**1**	1796	1041	755	1563.08	1364	199.08	247.91	555.92	0.446	446
	2	1788	1034	754	1563.08	1364	199.08	239.58	554.92	0.432	432
	3	1789	1034	755	1563.08	1364	199.08	241.61	555.92	0.435	435
										Average	**437**
7 days	**1**	1908	1114	794	1563.08	1364	199.08	247.91	594.92	0.417	417
	2	1898	1103	795	1563.08	1364	199.08	239.58	595.92	0.402	402
	3	1902	1110	792	1563.08	1364	199.08	241.61	592.92	0.407	407
										Average	**409**
14 days	**1**	1960	1164	796	1563.08	1364	199.08	247.91	596.92	0.415	415
	2	1950	1154	796	1563.08	1364	199.08	239.58	596.92	0.401	401
	3	1954	1155	799	1563.08	1364	199.08	241.61	599.92	0.403	403
										Average	**406**
28 days	**1**	1990	1260	730	1563.08	1364	199.08	247.91	530.92	0.467	467
	2	1981	1254	727	1563.08	1364	199.08	239.58	527.92	0.454	454
	3	1982	1239	743	1563.08	1364	199.08	241.61	543.92	0.444	444
										Average	**455**
90 days	**1**	2013	1223	790	1563.08	1364	199.08	247.91	590.92	0.420	420
	2	2003	1209	794	1563.08	1364	199.08	239.58	594.92	0.403	403
	3	2005	1212	793	1563.08	1364	199.08	241.61	593.92	0.407	407
										Average	**410**

Tabulated Results

	Block N.	**B001** Daily Average Density (kg/m³) 1	2	3	Average
Days	0	727	825	827	793
	1	790	827	829	815
	2	832	845	836	838
	3	839	832	829	834
	4	839	832	835	835
	7	839	834	835	836
	8	828	828	833	830
	9	832	834	833	833
	10	832	836	829	832
	11	830	832	833	832
	14	832	838	833	834
	15	830	830	838	833
	16	834	830	836	834
	17	830	832	827	830
	18	826	828	838	830
	53	786	840	811	812
	74	855	830	856	847
	91	843	838	835	839
	108	830	828	831	830

	Block N.	**B001 (90)** Density (kg/m³) 22	23	24	Average
Days	0	844	854	846	848
	7	847	856	858	854
	14	857	856	856	856
	28	855	854	846	852
	56	851	860	854	855
	90	847	849	854	850

	Block N.	**B002 (90)** Density (kg/m³) 25	26	27	Average
Days	0	679	680	677	678
	7	688	685	687	687
	14	693	683	692	689
	28	683	685	687	685
	56	682	686	692	687
	90	687	681	692	687

	Block N.	B003 (90) Density (kg/m³) 28	29	30	Average
Days	0	768	767	756	763
	7	769	761	769	766
	14	781	763	772	772
	28	783	769	761	771
	56	764	765	767	765
	90	787	769	767	774

	Block N.	HWD (90) Density (kg/m³) 2	2	4	Average
Days	0	448	461	457	455
	7	423	442	436	433
	14	417	432	426	425
	28	454	490	465	470
	90	419	435	429	427

	Block N.	SWD (90) Density (kg/m³) 1	2	3	Average
Days	0	446	432	435	437
	7	417	402	407	409
	14	415	401	403	406
	28	467	454	444	455
	90	420	403	407	410

	Block N.	TSW Daily Average Density (kg/m³) 1	2	3	Average
Days	0	420	387	392	400
	1	392	376	383	383
	2	408	375	384	389
	3	406	373	379	386
	4	405	372	377	385
	7	401	369	375	382
	8	401	368	373	381
	9	405	368	374	382
	10	400	368	374	381
	11	401	368	374	381
	14	401	368	373	381
	15	400	367	374	380
	16	400	368	374	381
	17	401	368	374	381
	18	401	368	373	381
	53	399	366	371	379
	74	399	366	372	379
	91	360	327	338	341
	108	398	366	374	379

Appendix C – Water Absorption Data

Data Calculations

B001 Blocks		11	12	13	14	15	16
		4	7	(11+12)	1	(14-13)	(15/12)*100
	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)
Immediate	1	1563.08	373.5	1936.53	1941	4.47	1.20
	2	1563.08	374.4	1937.49	1942	4.51	1.20
	3	1563.08	373.8	1936.92	1941	4.08	1.09
						Average	**1.16**
1 day	1	1563.08	373.5	1936.53	1967	30.47	8.16
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1941	4.08	1.09
						Average	**3.57**
2 days	1	1563.08	373.5	1936.53	1942	5.47	1.46
	2	1563.08	374.4	1937.49	1944	6.51	1.74
	3	1563.08	373.8	1936.92	1942	5.08	1.36
						Average	**1.52**
3 days	1	1563.08	373.5	1936.53	1944	7.47	2.00
	2	1563.08	374.4	1937.49	1944	6.51	1.74
	3	1563.08	373.8	1936.92	1942	5.08	1.36
						Average	**1.70**
4 days	1	1563.08	373.5	1936.53	1941	4.47	1.20
	2	1563.08	374.4	1937.49	1942	4.51	1.20
	3	1563.08	373.8	1936.92	1941	4.08	1.09
						Average	**1.16**
7 days	1	1563.08	373.5	1936.53	1944	7.47	2.00
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.70**
8 days	1	1563.08	373.5	1936.53	1944	7.47	2.00
	2	1563.08	374.4	1937.49	1944	6.51	1.74
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.79**
9 days	1	1563.08	373.5	1936.53	1943	6.47	1.73
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1944	7.08	1.89
						Average	**1.70**
10 days	1	1563.08	373.5	1936.53	1943	6.47	1.73
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.61**

11 days	1	1563.08	373.5	1936.53	1942	5.47	1.46
	2	1563.08	374.4	1937.49	1942	4.51	1.20
	3	1563.08	373.8	1936.92	1942	5.08	1.36
						Average	**1.34**
14 days	1	1563.08	373.5	1936.53	1943	6.47	1.73
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1942	5.08	1.36
						Average	**1.52**
15 days	1	1563.08	373.5	1936.53	1942	5.47	1.46
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1942	5.08	1.36
						Average	**1.43**
16 days	1	1563.08	373.5	1936.53	1944	7.47	2.00
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.70**
17 days	1	1563.08	373.5	1936.53	1942	5.47	1.46
	2	1563.08	374.4	1937.49	1943	5.51	1.47
	3	1563.08	373.8	1936.92	1944	7.08	1.89
						Average	**1.61**
18 days	1	1563.08	373.5	1936.53	1943	6.47	1.73
	2	1563.08	374.4	1937.49	1944	6.51	1.74
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.70**
53 days	1	1563.08	373.5	1936.53	1974	37.47	10.03
	2	1563.08	374.4	1937.49	1945	7.51	2.01
	3	1563.08	373.8	1936.92	1945	8.08	2.16
						Average	**4.73**
74 days	1	1563.08	373.5	1936.53	1944	7.47	2.00
	2	1563.08	374.4	1937.49	1944	6.51	1.74
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.79**
91 days	1	1563.08	373.5	1936.53	1943	6.47	1.73
	2	1563.08	374.4	1937.49	1944	6.51	1.74
	3	1563.08	373.8	1936.92	1943	6.08	1.63
						Average	**1.70**
108 days	1	1563.08	373.5	1936.53	1944	7.47	2.00
	2	1563.08	374.4	1937.49	1945	7.51	2.01
	3	1563.08	373.8	1936.92	1946	9.08	2.43
						Average	**2.14**

B001 Blocks (90)		11	12	13	14	15	16
		4	7	(11+12)	1	(14-13)	(15/12)*100
Immediate	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)
	22	1563.08	385.5	1948.54	1954	5.46	1.42
	23	1563.08	386.1	1949.19	1953	3.81	0.99
	24	1563.08	385.9	1949.00	1953	4.00	1.04
						Average	**1.15**
7 days	22	1563.08	385.5	1948.54	1954	5.46	1.42
	23	1563.08	386.1	1949.19	1954	4.81	1.25
	24	1563.08	385.9	1949.00	1954	5.00	1.30
						Average	**1.32**
14 days	22	1563.08	385.5	1948.54	1934	-14.54	-3.77
	23	1563.08	386.1	1949.19	1935	-14.19	-3.68
	24	1563.08	385.9	1949.00	1935	-14.00	-3.63
						Average	**-3.69**
28 days	22	1563.08	385.5	1948.54	1935	-13.54	-3.51
	23	1563.08	386.1	1949.19	1936	-13.19	-3.42
	24	1563.08	385.9	1949.00	1936	-13.00	-3.37
						Average	**-3.43**
56 days	22	1563.08	385.5	1948.54	1938	-10.54	-2.74
	23	1563.08	386.1	1949.19	1937	-12.19	-3.16
	24	1563.08	385.9	1949.00	1938	-11.00	-2.85
						Average	**-2.91**
90 days	22	1563.08	385.5	1948.54	1935	-13.54	-3.51
	23	1563.08	386.1	1949.19	1936	-13.19	-3.42
	24	1563.08	385.9	1949.00	1936	-13.00	-3.37
						Average	**-3.43**

B002 Blocks (90)		11 4	12 7	13 (11+12)	14 1	15 (14-13)	16 (15/12)*100
	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)
Immediate	25	1563.08	290.4	1853.43	1856	2.57	0.89
	26	1563.08	287.5	1850.55	1854	3.45	1.20
	27	1563.08	287.7	1850.81	1855	4.19	1.46
						Average	**1.18**
7 days	25	1563.08	290.4	1853.43	1859	5.57	1.92
	26	1563.08	287.5	1850.55	1855	4.45	1.55
	27	1563.08	287.7	1850.81	1856	5.19	1.80
						Average	**1.76**
14 days	25	1563.08	290.4	1853.43	1840	-13.43	-4.63
	26	1563.08	287.5	1850.55	1837	-13.55	-4.71
	27	1563.08	287.7	1850.81	1836	-14.81	-5.15
						Average	**-4.83**
28 days	25	1563.08	290.4	1853.43	1840	-13.43	-4.63
	26	1563.08	287.5	1850.55	1838	-12.55	-4.37
	27	1563.08	287.7	1850.81	1838	-12.81	-4.45
						Average	**-4.48**
56 days	25	1563.08	290.4	1853.43	1842	-11.43	-3.94
	26	1563.08	287.5	1850.55	1839	-11.55	-4.02
	27	1563.08	287.7	1850.81	1838	-12.81	-4.45
						Average	**-4.14**
90 days	25	1563.08	290.4	1853.43	1840	-13.43	-4.63
	26	1563.08	287.5	1850.55	1838	-12.55	-4.37
	27	1563.08	287.7	1850.81	1838	-12.81	-4.45
						Average	**-4.48**

B003 Blocks (90)		11 4	12 7	13 (11+12)	14 1	15 (14-13)	16 (15/12)*100
	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)
Immediate	28	1563.08	318.5	1881.56	1886	4.44	1.39
	29	1563.08	318.9	1882.00	1885	3.00	0.94
	30	1563.08	319.0	1882.06	1886	3.94	1.24
						Average	**1.19**
7 days	28	1563.08	318.5	1881.56	1887	5.44	1.71
	29	1563.08	318.9	1882.00	1888	6.00	1.88
	30	1563.08	319.0	1882.06	1887	4.94	1.55
						Average	**1.71**
14 days	28	1563.08	318.5	1881.56	1869	-12.56	-3.94
	29	1563.08	318.9	1882.00	1869	-13.00	-4.08
	30	1563.08	319.0	1882.06	1868	-14.06	-4.41
						Average	**-4.14**
28 days	28	1563.08	318.5	1881.56	1869	-12.56	-3.94
	29	1563.08	318.9	1882.00	1869	-13.00	-4.08
	30	1563.08	319.0	1882.06	1869	-13.06	-4.09
						Average	**-4.04**
56 days	28	1563.08	318.5	1881.56	1871	-10.56	-3.32
	29	1563.08	318.9	1882.00	1871	-11.00	-3.45
	30	1563.08	319.0	1882.06	1871	-11.06	-3.47
						Average	**-3.41**
90 days	28	1563.08	318.5	1881.56	1869	-12.56	-3.94
	29	1563.08	318.9	1882.00	1869	-13.00	-4.08
	30	1563.08	319.0	1882.06	1869	-13.06	-4.09
						Average	**-4.04**

TSW Blocks		11	12	13	14	15	16
		4	7	(11+12)	1	(14-13)	(15/12)*100
	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)
Immediate	1	1563.08	304.2	1867.31	1880	12.69	4.17
	2	1563.08	278.4	1841.44	1854	12.56	4.51
	3	1563.08	284.2	1847.30	1858	10.70	3.76
						Average	4.15
1 day	1	1563.08	304.2	1867.31	1924	56.69	18.63
	2	1563.08	278.4	1841.44	1896	54.56	19.60
	3	1563.08	284.2	1847.30	1900	52.70	18.54
						Average	18.93
2 days	1	1563.08	304.2	1867.31	1941	73.69	24.22
	2	1563.08	278.4	1841.44	1910	68.56	24.63
	3	1563.08	284.2	1847.30	1910	62.70	22.06
						Average	23.64
3 days	1	1563.08	304.2	1867.31	1951	83.69	27.51
	2	1563.08	278.4	1841.44	1919	77.56	27.86
	3	1563.08	284.2	1847.30	1924	76.70	26.99
						Average	27.45
4 days	1	1563.08	304.2	1867.31	1958	90.69	29.81
	2	1563.08	278.4	1841.44	1927	85.56	30.74
	3	1563.08	284.2	1847.30	1930	82.70	29.10
						Average	29.88
7 days	1	1563.08	304.2	1867.31	1989	121.69	40.00
	2	1563.08	278.4	1841.44	1956	114.56	41.16
	3	1563.08	284.2	1847.30	1961	113.70	40.00
						Average	40.39
8 days	1	1563.08	304.2	1867.31	2000	132.69	43.62
	2	1563.08	278.4	1841.44	1968	126.56	45.47
	3	1563.08	284.2	1847.30	1972	124.70	43.87
						Average	44.32
9 days	1	1563.08	304.2	1867.31	2001	133.69	43.94
	2	1563.08	278.4	1841.44	1976	134.56	48.34
	3	1563.08	284.2	1847.30	1981	133.70	47.04
						Average	46.44
10 days	1	1563.08	304.2	1867.31	2016	148.69	48.87
	2	1563.08	278.4	1841.44	1984	142.56	51.21
	3	1563.08	284.2	1847.30	1987	139.70	49.15
						Average	49.75
11	1	1563.08	304.2	1867.31	2023	155.69	51.18

days	2	1563.08	278.4	1841.44	1991	149.56	53.73
	3	1563.08	284.2	1847.30	1995	147.70	51.97
						Average	**52.29**
14 days	1	1563.08	304.2	1867.31	2039	171.69	56.43
	2	1563.08	278.4	1841.44	2009	167.56	60.20
	3	1563.08	284.2	1847.30	2013	165.70	58.30
						Average	**58.31**
15 days	1	1563.08	304.2	1867.31	2045	177.69	58.41
	2	1563.08	278.4	1841.44	2015	173.56	62.35
	3	1563.08	284.2	1847.30	2017	169.70	59.71
						Average	**60.15**
16 days	1	1563.08	304.2	1867.31	2049	181.69	59.72
	2	1563.08	278.4	1841.44	2018	176.56	63.43
	3	1563.08	284.2	1847.30	2020	172.70	60.76
						Average	**61.30**
17 days	1	1563.08	304.2	1867.31	2050	182.69	60.05
	2	1563.08	278.4	1841.44	2021	179.56	64.51
	3	1563.08	284.2	1847.30	2023	175.70	61.82
						Average	**62.12**
18 days	1	1563.08	304.2	1867.31	2054	186.69	61.36
	2	1563.08	278.4	1841.44	2025	183.56	65.94
	3	1563.08	284.2	1847.30	2028	180.70	63.58
						Average	**63.63**
53 days	1	1563.08	304.2	1867.31	2106	238.69	78.46
	2	1563.08	278.4	1841.44	2080	238.56	85.70
	3	1563.08	284.2	1847.30	2085	237.70	83.63
						Average	**82.60**
74 days	1	1563.08	304.2	1867.31	2128	260.69	85.69
	2	1563.08	278.4	1841.44	2100	258.56	92.89
	3	1563.08	284.2	1847.30	2104	256.70	90.32
						Average	**89.63**
91 days	1	1563.08	304.2	1867.31	2135	267.69	87.99
	2	1563.08	278.4	1841.44	2106	264.56	95.04
	3	1563.08	284.2	1847.30	2111	263.70	92.78
						Average	**91.94**
108 days	1	1563.08	304.2	1867.31	2151	283.69	93.25
	2	1563.08	278.4	1841.44	2122	280.56	100.79
	3	1563.08	284.2	1847.30	2128	280.70	98.76
						Average	**97.60**

HWD Blocks (90)		11	12	13	14	15	16	17
		4	7	(11+12)	1	(14-13)	(15/12)*100	Added ≠ immediate value
	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)	Water Absorption (%)
Immediate	2	1563.08	207.6	1770.65	1754	-16.65	-8.02	0.00
	3	1563.08	213.8	1776.85	1761	-15.85	-7.41	0.00
	4	1563.08	211.3	1774.42	1758	-16.42	-7.77	0.00
						Average	**-7.74**	**0.00**
7 days	2	1563.08	207.6	1770.65	1828	57.35	27.63	35.65
	3	1563.08	213.8	1776.85	1831	54.15	25.33	32.75
	4	1563.08	211.3	1774.42	1830	55.58	26.30	34.07
						Average	**26.42**	**34.15**
14 days	2	1563.08	207.6	1770.65	1877	106.35	51.24	59.26
	3	1563.08	213.8	1776.85	1882	105.15	49.19	56.60
	4	1563.08	211.3	1774.42	1883	108.58	51.37	59.15
						Average	**50.60**	**58.34**
28 days	2	1563.08	207.6	1770.65	1906	135.35	65.21	73.23
	3	1563.08	213.8	1776.85	1909	132.15	61.82	69.23
	4	1563.08	211.3	1774.42	1913	138.58	65.57	73.34
						Average	**64.20**	**71.93**
90 days	2	1563.08	207.6	1770.65	1928	157.35	75.81	83.83
	3	1563.08	213.8	1776.85	1932	155.15	72.58	79.99
	4	1563.08	211.3	1774.42	1932	157.58	74.56	82.33
						Average	**74.32**	**82.05**

Assuming the Immidite absorption as 0 the differential innitial aborption was added to the values.

SWD Blocks (90)		11	12	13	14	15	16	17
		4	7	(11+12)	1	(14-13)	(15/12)*100	Added ≠ immediate value
	Number	Steel wt scale(g)	Material wt scale (g)	Combined wt scale (g)	Combined wt in air (g)	Difference in wt (g)	Water Absorption (%)	Water Absorption (%)
Immediate	1	1563.08	247.9	1810.99	1796	-14.99	-6.05	0.00
	2	1563.08	239.6	1802.66	1788	-14.66	-6.12	0.00
	3	1563.08	241.6	1804.69	1789	-15.69	-6.49	0.00
						Average	**-6.22**	**0.00**
7 days	1	1563.08	247.9	1810.99	1908	97.01	39.13	45.18
	2	1563.08	239.6	1802.66	1898	95.34	39.79	45.91
	3	1563.08	241.6	1804.69	1902	97.31	40.28	46.77
						Average	**39.73**	**45.95**
14 days	1	1563.08	247.9	1810.99	1960	149.01	60.11	66.15
	2	1563.08	239.6	1802.66	1950	147.34	61.50	67.62
	3	1563.08	241.6	1804.69	1954	149.31	61.80	68.29
						Average	**61.14**	**67.35**
28 days	1	1563.08	247.9	1810.99	1990	179.01	72.21	78.26
	2	1563.08	239.6	1802.66	1981	178.34	74.44	80.56
	3	1563.08	241.6	1804.69	1982	177.31	73.39	79.88
						Average	**73.35**	**79.56**
90 days	1	1563.08	247.9	1810.99	2013	202.01	81.49	87.53
	2	1563.08	239.6	1802.66	2003	200.34	83.62	89.74
	3	1563.08	241.6	1804.69	2005	200.31	82.91	89.40
						Average	**82.67**	**88.89**

Assuming the Immidite absorption as 0 the differential innitial aborption was added to the values.

Tabulated Results

	Block N.	B001 Daily Average Water Absorption (%) 1	2	3	Average
Days	0	1.20	1.20	1.09	1.16
	1	8.16	1.47	1.09	3.57
	2	1.46	1.74	1.36	1.52
	3	2.00	1.74	1.36	1.70
	4	1.20	1.20	1.09	1.16
	7	2.00	1.47	1.63	1.70
	8	2.00	1.74	1.63	1.79
	9	1.73	1.47	1.89	1.70
	10	1.73	1.47	1.63	1.61
	11	1.46	1.20	1.36	1.34
	14	1.73	1.47	1.36	1.52
	15	1.46	1.47	1.36	1.43
	16	2.00	1.47	1.63	1.70
	17	1.46	1.47	1.89	1.61
	18	1.73	1.74	1.63	1.70
	53	10.03	2.01	2.16	4.73
	74	2.00	1.74	1.63	1.79
	91	1.73	1.74	1.63	1.70
	108	2.00	2.01	2.43	2.14
		Rate of H_2O absorption			

	Block N.	B001 (90) Water Absorption (%) 22	23	24	Average
Days	0	1.42	0.99	1.04	1.15
	7	1.42	1.25	1.30	1.32
	14	-3.77	-3.68	-3.63	-3.692
	28	-3.51	-3.42	-3.37	-3.433
	56	-2.74	-3.16	-2.85	-2.914
	90	-3.51	-3.42	-3.37	-3.433
		Rate of H_2O absorption			

	Block N.	B002 (90) Water Absorption (%) 25	26	27	Average
Days	0	0.89	1.20	1.46	1.18
	7	1.92	1.55	1.80	1.76
	14	-4.63	-4.71	-5.15	-4.83
	28	-4.63	-4.37	-4.45	-4.48
	56	-3.94	-4.02	-4.45	-4.14
	90	-4.63	-4.37	-4.45	-4.48
		Rate of H_2O absorption			

		B003 (90) Water Absorption (%)			
	Block N.	**28**	**29**	**30**	**Average**
Days	**0**	1.39	0.94	1.24	1.19
	7	1.71	1.88	1.55	1.71
	14	-3.94	-4.08	-4.41	-4.14
	28	-3.94	-4.08	-4.09	-4.04
	56	-3.32	-3.45	-3.47	-3.41
	90	-3.94	-4.08	-4.09	-4.04
		Rate of H_2O absorption			

		HWD (90) Water Absorption (%)			
	Block N.	**2**	**3**	**4**	**Average**
Days	**0**	0	0	0	0
	7	36	33	34	34
	14	59	57	59	58
	28	73	69	73	72
	90	84	80	82	82
		Rate of H_2O absorption			

		SWD (90) Water Absorption (%)			
	Block N.	1	2	3	Average
Days	**0**	0	0	0	0
	7	45	46	47	46
	14	66	68	68	67
	28	78	81	80	80
	90	88	90	89	89
		Rate of H_2O absorption			

		TSW Daily Average Water Absorption (%)			
	Block N.	**1**	**2**	**3**	**Average**
Days	**0**	4	5	4	4
	1	19	20	19	19
	2	24	25	22	24
	3	28	28	27	27
	4	30	31	29	30
	7	40	41	40	40
	8	44	45	44	44
	9	44	48	47	46
	10	49	51	49	50
	11	51	54	52	52
	14	56	60	58	58
	15	58	62	60	60
	16	60	63	61	61
	17	60	65	62	62
	18	61	66	64	64
	53	78	86	84	83
	74	86	93	90	90
	91	88	95	93	92
	108	93	100	99	97
		Rate of H_2O absorption			

Appendix D – Compressive Strength Data

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B001 (a) - 10kN (Load control method)	8	654.539	35.323	35323.3	53.967	53.510	0.92	22.89	4.00E-02	4.16E-02	1284.94
	9	591.923	29.471	29471.2	49.789		1.00	23.44	4.25E-02		
	10	605.756	34.391	34391.3	56.774		1.02	24.01	4.25E-02		
	11	597.979	21.709	21708.9	36.304	37.214	0.81	25.43	3.19E-02	3.31E-02	1124.54
	12	591.932	25.848	25847.5	43.666		1.04	27.63	3.76E-02		
	13	590.519	18.704	18703.5	31.673		0.76	25.52	2.98E-02		
	17	334.403	12.891	12891.2	38.550	41.265	0.48	24.34	1.97E-02	3.26E-02	1265.58
	18	326.486	13.808	13807.5	42.291		1.00	25.01	4.00E-02		
	19	330.335	14.189	14188.9	42.953		0.96	25.19	3.81E-02		

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B001 (a) - 20kN (Load control method)	20	599.451	28.200	28200	47.043	46.480	0.78	23.52	3.32E-02	3.67E-02	1266.23
	21	627.822	28.380	28380	45.204		0.88	23.45	3.73E-02		
	22	611.733	28.870	28870	47.194		0.93	23.46	3.97E-02		
	23	603.489	16.920	16920	28.037	35.436	0.78	25.70	3.04E-02	2.90E-02	1222.55
	24	585.701	22.780	22780	38.894		0.84	25.78	3.26E-02		
	25	587.908	23.150	23150	39.377		0.63	26.23	2.40E-02		
	26	329.879	12.600	12600	38.196	54.087	0.90	24.90	3.61E-02	3.80E-02	1423.19
	27	321.734	19.420	19420	60.360		1.08	24.16	4.47E-02		
	28	321.646	20.490	20490	63.703		0.83	25.03	3.32E-02		

(dark grey)	Axial Load (Y-Y)
(white)	Transversal Load (X-X)
(light grey)	Vertical Load (Z-Z)

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B001 (b) - 10kN (Load control method)	37	611.223	25.441	25441.3	41.624	45.205	0.81	25.21	3.21E-02	3.40E-02	1329.63
	38	583.191	25.814	25813.7	44.263		0.87	25.13	3.46E-02		
	39	567.202	28.228	28228.2	49.767		0.82	24.48	3.35E-02		
	40	582.935	26.330	26329.5	45.167		0.89	24.89	3.58E-02		
	45	616.348	16.592	16592	26.920	27.974	0.61	25.54	2.39E-02	2.65E-02	1057.33
	46	601.679	21.701	21700.9	36.067		0.80	25.65	3.12E-02		
	47	616.018	16.915	16914.9	27.458		0.65	25.55	2.54E-02		
	48	620.365	13.308	13307.5	21.451		0.65	25.68	2.53E-02		
	29	340.847	14.728	14728.4	43.211	49.839	0.49	24.11	2.03E-02	2.41E-02	2065.84
	30	341.460	19.753	19752.7	57.848		0.52	23.44	2.22E-02		
	31	365.000	21.183	21182.6	58.035		0.49	23.38	2.10E-02		
	32	360.777	14.527	14526.5	40.265		0.80	24.22	3.30E-02		

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B001 (b) - 20kN (Load control method)	41	584.708	29.305	29305.1	50.119	47.900	0.83	24.80	3.35E-02	3.34E-02	1434.44
	42	593.587	26.755	26755.3	45.074		0.82	24.84	3.30E-02		
	43	582.771	26.310	26310	45.146		0.85	25.10	3.39E-02		
	44	556.162	28.508	28508.1	51.259		0.83	24.98	3.32E-02		
	49	600.224	23.057	23056.7	38.414	34.172	0.76	25.70	2.96E-02	2.92E-02	1168.74
	50	615.454	15.466	15466.1	25.130		0.74	25.54	2.90E-02		
	51	604.238	23.549	23549	38.973		0.75	25.72	2.92E-02		
	33	343.914	19.098	19098	55.531	46.123	0.58	23.32	2.49E-02	2.93E-02	1573.60
	34	359.386	19.903	19902.8	55.380		0.70	23.40	2.99E-02		
	35	330.697	12.105	12105	36.604		0.73	24.17	3.02E-02		
	36	326.049	12.056	12055.6	36.975		0.78	24.20	3.22E-02		

(dark grey)	Axial Load (Y-Y)
(white)	Transversal Load (X-X)
(light grey)	Vertical Load (Z-Z)

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B002 - 10kN (Load control method)	5	561.340	24.455	24454.5	43.565	37.290	0.88	27.15	3.24E-02	3.72E-02	1002.01
	6	572.152	20.614	20614	36.029		0.94	26.34	3.57E-02		
	7	606.943	19.192	19192	31.621		1.20	26.87	4.47E-02		
	8	596.694	22.642	22641.7	37.945		0.98	27.14	3.61E-02		
	9	636.374	12.317	12317.2	19.355	27.008	0.70	26.82	2.61E-02	2.77E-02	975.09
	10	609.653	20.789	20788.6	34.099		0.75	27.02	2.78E-02		
	11	623.078	21.162	21162.3	33.964		0.80	26.90	2.97E-02		
	12	652.784	13.457	13456.7	20.614		0.72	26.48	2.72E-02		
	1	396.037	18.555	18554.5	46.850	41.067	0.76	22.54	3.37E-02	3.01E-02	1365.19
	2	396.949	19.247	19247.4	48.488		0.50	22.45	2.23E-02		
	3	396.263	11.362	11361.9	28.673		0.82	24.03	3.41E-02		
	4	395.570	15.924	15923.9	40.256		0.68	22.51	3.02E-02		

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B002 -20kN (Load control method)	13	573.149	24.916	24916.3	43.473	41.956	0.93	27.19	3.42E-02	3.40E-02	1232.25
	14	582.696	26.164	26164.1	44.902		0.83	26.54	3.13E-02		
	15	590.603	23.045	23045	39.019		1.00	27.06	3.70E-02		
	16	575.325	23.261	23261.2	40.431		0.92	27.26	3.37E-02		
	22	571.000	13.372	13372.1	23.419	18.617	0.65	25.96	2.50E-02	2.18E-02	854.29
	23	608.484	9.712	9711.57	15.960		0.55	27.95	1.97E-02		
	24	599.283	10.012	10012.4	16.707		0.54	27.62	1.96E-02		
	25	607.076	11.158	11158.3	18.380		0.63	27.51	2.29E-02		
	18	385.072	7.308	7307.66	18.977	21.067	0.55	24.09	2.28E-02	2.70E-02	779.91
	19	397.490	8.472	8471.85	21.313		0.70	24.05	2.91E-02		
	20	388.127	8.675	8675	22.351		0.75	24.06	3.12E-02		
	21	390.027	8.435	8435.39	21.628		0.60	24.07	2.49E-02		

[dark grey]	Axial Load (Y-Y)
[white]	Transversal Load (X-X)
[light grey]	Vertical Load (Z-Z)

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B003 -10kN (Load control method)	1	617.258	22.982	22981.8	37.232	29.459	0.92	27.17	3.39E-02	3.75E-02	785.73
	2	597.263	14.455	14454.8	24.202		1.45	26.92	5.39E-02		
	3	598.170	17.290	17289.8	28.905		0.81	26.92	3.01E-02		
	4	565.947	15.562	15561.7	27.497		0.87	27.07	3.21E-02		
	9	646.973	8.733	8732.88	13.498	15.780	0.50	25.39	1.97E-02	2.40E-02	656.60
	10	664.075	10.586	10585.9	15.941		0.72	26.34	2.73E-02		
	11	646.366	7.819	7818.72	12.096		0.61	24.99	2.44E-02		
	12	619.402	13.369	13368.8	21.583		0.65	26.33	2.47E-02		
	5	386.511	11.237	11237.1	29.073	39.367	0.70	23.28	3.01E-02	2.81E-02	1400.97
	6	285.295	11.556	11556.1	40.506		0.70	23.06	3.04E-02		
	7	281.505	12.235	12234.6	43.461		0.65	23.11	2.81E-02		
	8	282.618	12.556	12556.2	44.428		0.55	23.07	2.38E-02		

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
B003 -20kN (Load control method)	13	590.550	19.457	19457.4	32.948	31.933	0.87	27.20	3.20E-02	3.22E-02	992.53
	14	612.513	18.334	18333.6	29.932		0.80	27.22	2.94E-02		
	15	570.895	17.559	17558.8	30.757		0.93	27.58	3.37E-02		
	16	620.888	21.170	21169.8	34.096		0.90	26.78	3.36E-02		
	21	660.027	11.076	11076.3	16.782	20.071	0.65	26.33	2.47E-02	2.72E-02	736.57
	22	612.432	13.778	13778.4	22.498		0.80	26.57	3.01E-02		
	23	624.477	13.872	13872.2	22.214		0.67	26.32	2.55E-02		
	24	667.167	12.537	12537.4	18.792		0.76	26.44	2.87E-02		
	20	376.748	9.359	9358.66	24.841	42.889	0.92	24.31	3.78E-02	3.67E-02	1167.92
	25	448.542	21.583	21582.6	48.117		0.55	22.70	2.42E-02		
	26	451.596	21.475	21474.5	47.552		0.88	22.73	3.87E-02		
	27	444.123	22.671	22671.3	51.047		1.05	22.78	4.61E-02		

(dark grey)	Axial Load (Y-Y)
(white)	Transversal Load (X-X)
(light grey)	Vertical Load (Z-Z)

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
HWD -10kN (Load control method)	2	602.092	31.659	31658.8	52.581	47.942	0.50	25.87	1.93E-02	2.06E-02	2322.44
	3	579.964	27.041	27040.7	46.625		0.46	25.79	1.78E-02		
	4	578.640	27.283	27282.7	47.150		0.70	25.41	2.76E-02		
	5	581.302	26.398	26398.1	45.412		0.46	25.77	1.79E-02		
	6	550.534	3.297	3297.14	5.989	5.520	0.25	28.30	8.84E-03	9.62E-03	573.76
	7	553.142	2.978	2978.42	5.385		0.30	29.18	1.03E-02		
	8	551.732	2.933	2932.89	5.316		0.28	28.38	9.87E-03		
	9	553.110	2.981	2981.03	5.390		0.27	28.43	9.50E-03		
	10	387.956	4.779	4778.85	12.318	11.333	0.37	21.56	1.72E-02	2.24E-02	504.92
	11	396.931	4.437	4436.71	11.178		0.43	21.48	2.00E-02		
	12	397.442	4.381	4380.78	11.022		0.70	21.43	3.27E-02		
	13	390.617	4.223	4223.37	10.812		0.43	21.57	1.99E-02		

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
HWD -20kN (Load control method)	14	597.594	32.714	32713.7	54.742	52.106	0.63	25.63	2.46E-02	2.16E-02	2415.22
	15	576.880	28.959	28958.8	50.199		0.53	25.69	2.06E-02		
	16	576.646	30.006	30005.6	52.035		0.58	25.79	2.25E-02		
	17	576.268	29.649	29648.9	51.450		0.48	25.82	1.86E-02		
	18	557.874	3.960	3960.36	7.099	6.349	0.30	29.39	1.02E-02	1.13E-02	562.44
	19	557.236	2.795	2795.08	5.016		0.33	28.49	1.16E-02		
	20	556.343	3.717	3716.89	6.681		0.40	27.48	1.46E-02		
	21	556.018	3.670	3670.02	6.601		0.25	28.39	8.81E-03		
	22	408.315	4.373	4373.09	10.710	10.382	0.38	21.43	1.77E-02	1.85E-02	562.25
	23	400.310	4.140	4140.04	10.342		0.36	21.57	1.67E-02		
	24	410.310	4.141	4141.34	10.093		0.45	21.46	2.10E-02		

	Axial Load (Y-Y)
	Transversal Load (X-X)
	Vertical Load (Z-Z)

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
SWD -10kN (Load control method)	3	844.169	40.502	40502.2	47.979	47.098	0.60	26.20	2.29E-02	2.18E-02	2162.29
	4	813.385	38.678	38678.4	47.552		0.54	25.94	2.08E-02		
	5	818.518	37.908	37908.3	46.313		0.58	25.95	2.23E-02		
	6	850.531	39.589	39589	46.546		0.55	26.13	2.11E-02		
	7	702.187	2.826	2826.22	4.025	4.167	0.64	31.04	2.06E-02	1.81E-02	230.68
	8	697.618	2.471	2471.08	3.542		0.70	30.83	2.27E-02		
	9	710.472	3.785	3784.97	5.327		0.40	31.81	1.26E-02		
	10	709.291	2.675	2675.32	3.772		0.52	31.80	1.64E-02		
	11	679.710	6.833	6832.94	10.053	7.044	0.37	27.17	1.36E-02	1.85E-02	379.83
	12	647.720	4.208	4207.76	6.496		0.64	27.26	2.35E-02		
	13	631.913	3.429	3428.53	5.426		0.43	27.19	1.58E-02		
	14	648.579	4.022	4021.73	6.201		0.58	27.27	2.13E-02		

				Load*1000	F/A	σ Aver			ΔL/L	ε Aver	σ/ε
	Cube Number	Total Area (mm^2)	Load (kN)	Load (N)	Stress - σ (N/mm^2)	Mean Stress (N/mm^2)	ΔL (mm)	L (mm)	Strain - ε	Mean Strain - ε	Young's Modulus - E (N/mm^2)
SWD -20kN (Load control method)	15	788.552	36.881	36880.6	46.770	49.198	0.54	26.11	2.07E-02	2.04E-02	2414.43
	16	802.251	39.480	39480.1	49.212		0.52	26.11	1.99E-02		
	17	820.214	45.380	45380	55.327		0.54	25.89	2.09E-02		
	18	818.452	37.227	37227	45.485		0.52	25.95	2.00E-02		
	23	708.448	2.413	2413.43	3.407	3.446	0.52	31.29	1.66E-02	1.97E-02	174.90
	24	701.121	2.706	2706.45	3.860		0.66	31.31	2.11E-02		
	25	709.520	2.344	2344.4	3.304		0.55	31.79	1.73E-02		
	26	692.160	2.223	2223.29	3.212		0.74	31.09	2.38E-02		
	19	683.485	3.596	3595.81	5.261	5.912	0.62	27.08	2.29E-02	1.89E-02	312.09
	20	653.191	3.868	3867.92	5.922		0.35	27.23	1.29E-02		
	21	685.507	4.145	4145.25	6.047		0.64	26.94	2.38E-02		
	22	653.184	4.193	4193.42	6.420		0.44	27.05	1.63E-02		

(dark grey)	Axial Load (Y-Y)
(white)	Transversal Load (X-X)
(light grey)	Vertical Load (Z-Z)

Appendix E – Flexural Strength Data

B001	**number**	**length (mm)**	**effective length (mm)**	**width (mm)**	**thickness (mm)**	**weight (g)**
	1	725	525	124	25	1611.88
	2	725	525	124	25	1642.84
	3	725	525	124	25	1667.49

SWD	**number**	**length (mm)**	**effective length (mm)**	**width (mm)**	**thickness (mm)**	**weight (g)**
	1	750	567	141	27	1130.77
	2	750	567	141	27	1038.55
	3	750	567	141	27	1058.57

B001

Sample 1	**Displacement (mm)**		**Sample 2**	**Displacement (mm)**			**Sample 3**	**Displacement (mm)**		
Load (kN)	Dial	Jack	Load (kN)	Dial	Dial	Jack	Load (kN)	Dial	Dial	Jack
0	0	0	0	12.03	0	0	0	12.63	0	0
0.2	1.52	1.9	0.2	13.48	1.45	1.45	0.2	14.04	1.41	1.35
0.4	3.96	3.2	0.4	14.91	2.88	2.74	0.4	15.42	2.79	2.68
0.6	4.48	1.7	0.6	16.4	4.37	4.08	0.6	16.85	4.22	3.94
0.8	5.92	5.9	0.8	17.82	5.79	5.35	0.8	18.85	6.22	5.2
1	7.42	7.3	1	19.3	7.27	6.68	1	19.65	7.02	6.45
1.2	8.91	8.6	1.2	20.77	8.74	8	1.2	21.07	8.44	8.84
1.4	10.4	10	1.4	22.2	10.17	9.3	1.4	22.46	9.83	10.3
1.6		11.35	1.6	23.7	11.67	10.65	1.6	23.96	11.33	11.62
1.8		12.7	1.8			12.16	1.8			12.94
2		14.1	2			13.5	2			14.3
2.2		15.55	2.2			14.95	2.2			15.68
2.4		16.97	2.4			16.35	2.4			17.12
2.6		18.4	2.6			18.02	2.6			18.45
2.8		20.3	2.8			19.6	2.8			19.45
2.8		21.12	3			21.02	3			19.85
3.2			3.2			23.8	3.2			21.32
3.4			3.4				3.4			

SWD

Sample 1	**Displacement (mm)**			**Sample 2**	**Displacement (mm)**			**Sample 3**	**Displacement (mm)**		
Load (kN)	Dial	Dial	Jack	Load (kN)	Dial	Dial	Jack	Load (kN)	Dial	Dial	Jack
0	10	0	0	0	12	0	0	0	7.63	0	0
0.5	10.83	0.83	0.9	0.5	13.8	1.8	2.67	0.5	8.43	0.8	1.86
1	11.62	1.62	1.7	1	15.25	3.25	4.14	1	10.83	3.2	3.3
1.5	12.38	2.38	2.43	1.5	16.12	4.12	5.06	1.5	11.77	4.14	4.25
2	13.12	3.12	3.17	2	16.94	4.94	6.75	2	12.65	5.02	5.13
2.5	13.99	3.99	3.9	2.5	17.73	5.73	7.56	2.5	13.48	5.85	5.94
3	14.77	4.77	4.7	3	18.5	6.5	8.35	3	14.34	6.71	6.7
3.5	15.57	5.57	5.47	3.5	19.28	7.28	9.11	3.5	15.14	7.51	7.54
4	16.37	6.37	6.22	4	20.08	8.08	9.97	4	15.95	8.32	8.34
4.5	17.18	7.18	7	4.5	20.87	8.87	10.78	4.5	16.78	9.15	9.15
5	18	8	7.82	5	21.61	9.61	11.69	5	17.57	9.94	9.92
5.5	18.87	8.87	8.61	5.5	22.54	10.54	12.35	5.5	18.45	10.82	10.73
6	19.69	9.69	9.4	6	23.32	11.32	13.33	6	19.37	11.74	11.68
6.5	20.51	10.51	10.2	6.5	24.12	12.12	14.05	6.5	20.17	12.54	12.53
7	21.37	11.37	11.25	7	24.95	12.95	14.86	7	21.1	13.47	13.36
7.5			13.07	7.5			15.74	7.5	22.17	14.54	14.24
8			14.18	8			16.55	9.7			20
8.5				8.5			17.32	8.5			
9				9			18.32	9			
9.5				9.5			19.32	9.5			
10				10			20.41	10			
10.5				10.5			22.12	10.5			
11				11.6			23.58	11			
11.5				11.5				11.5			

Average Load/Deflection values

B001		**SWD**	
Load (kN)	Deflection (mm)	**Load (kN)**	Deflection (mm)
0.0	0.0	**0.0**	0.0
1.6	0.2	**1.8**	0.5
2.9	0.4	**3.0**	1.0
3.2	0.6	**3.9**	1.5
5.5	0.8	**5.0**	2.0
6.8	1.0	**5.8**	2.5
8.5	1.2	**6.6**	3.0
9.9	1.4	**7.4**	3.5
11.2	1.6	**8.2**	4.0
12.6	1.8	**9.0**	4.5
14.0	2.0	**9.8**	5.0

15.4	2.2	**10.6**	5.5
16.8	2.4	**11.5**	6.0
18.3	2.6	**12.3**	6.5
19.8	2.8	**13.2**	7.0
20.7	2.9	**14.4**	7.5
22.6	3.2	**16.9**	8.6
		17.3	8.5
		18.3	9.0
		19.3	9.5
		20.4	10.0
		22.1	10.5
		23.6	11.2

$$f_m = \frac{3F_a}{bh^2} = N/mm^2$$

			1	2 (1*1000)	3	4	5 (3/4)
Dimensions (mm)		Plank N.	Peak load (*F*) (kN)	Peak load (*F*) (N)	*3Fa*	*bh2*	*fm* (N/mm2)
h=27	SWD	1	10.7	10700	6500250	102789	63.238771
b=141		2	11.6	11600	7047000	102789	68.55792
a=202.5		3	9.7	9700	5892750	102789	57.328605
h=25	B001	1	2.8	2800	1575000	77500	20.322581
b= 124		2	3.2	3200	1800000	77500	23.225806
a=187.5		3	3.2	3200	1800000	77500	23.225806

	fm (N/mm2)			
	Plank 1	Plank 2	Plank 3	Average
SWD	63.24	68.56	57.33	63.04
B001	20.32	23.23	23.23	22.26

Appendix F – Thermal Conductivity Data

LASERCOMP FOX200

Polymer Decking Batch001 Sample 1(31)

Wednesday, August 08, 2012, Time 14:35

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB001N31
Sample Thickness: 2.504cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Set points: 8

Block Averages for set point 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-20.01	5.00	-4305	4399	0.1120
-pe-	-20.02	4.98	-4295	4409	0.1120
-pe-	-20.03	4.97	-4283	4422	0.1120
-pe-	-20.03	4.97	-4272	4435	0.1121
-pe-	-20.03	4.97	-4261	4449	0.1121
-pe-	-20.02	4.98	-4255	4458	0.1121
-pe-	-20.01	4.98	-4250	4465	0.1122
-pe-	-20.01	4.99	-4247	4469	0.1121
-pe-	-20.01	5.00	-4246	4470	0.1121
-pe-	-20.00	5.00	-4248	4468	0.1121

Wednesday, August 08, 2012, Time 16:26

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.01 °C
Results Upper: 0.1134 W/mK
Temperature Lower: 5.00 °C

Results Lower: 0.1108 W/mK
Percent Difference: 2.32%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-4350	4672	0.1145
-te-	-10.01	15.00	-4376	4633	0.1144
-pe-	-9.99	15.01	-4384	4629	0.1144
-pe-	-9.97	15.03	-4398	4615	0.1144
-pe-	-9.98	15.04	-4412	4600	0.1144
-pe-	-9.98	15.03	-4420	4586	0.1143
-pe-	-9.99	15.02	-4424	4578	0.1142
-pe-	-10.00	15.01	-4427	4573	0.1143
-pe-	-10.00	15.01	-4426	4572	0.1142
-pe-	-10.00	15.00	-4428	4572	0.1143

Wednesday, August 08, 2012, Time 17:58

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.1160 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.1125 W/mK
Percent Difference: 3.01%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-4502	4819	0.1168
-pe-	0.00	25.01	-4507	4814	0.1167
-pe-	0.02	25.03	-4517	4803	0.1167
-pe-	0.02	25.03	-4528	4789	0.1167

-pe-	0.01	25.03	-4537	4775	0.1166
-pe-	0.00	25.03	-4542	4764	0.1165
-pe-	0.00	25.02	-4546	4757	0.1165
-pe-	0.00	25.01	-4550	4751	0.1165
-pe-	-0.01	25.01	-4550	4749	0.1165
-pe-	-0.01	25.00	-4550	4749	0.1165

Wednesday, August 08, 2012, Time 19:36

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.1170 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.1160 W/mK
Percent Difference: 0.82%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	10.01	35.02	-4652	5006	0.1194
-pe-	10.01	35.04	-4656	4992	0.1192
-pe-	10.01	35.04	-4656	4978	0.1191
-pe-	10.02	35.04	-4665	4964	0.1191
-pe-	10.03	35.04	-4680	4949	0.1191
-pe-	10.03	35.03	-4691	4937	0.1191
-pe-	10.02	35.02	-4697	4930	0.1191
-pe-	10.01	35.02	-4700	4925	0.1191
-pe-	10.00	35.01	-4697	4922	0.1190
-pe-	10.00	35.01	-4694	4922	0.1190

Wednesday, August 08, 2012, Time 21:18

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.00 °C
Results Upper: 0.1186 W/mK
Temperature Lower: 35.01 °C
Results Lower: 0.1194 W/mK
Percent Difference: 0.66%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	20.00	45.02	-4688	5261	0.1214
-te-	20.00	45.00	-4723	5195	0.1212
-te-	20.00	45.02	-4759	5172	0.1213
-pe-	19.99	45.01	-4755	5169	0.1212
-pe-	20.00	45.02	-4753	5166	0.1211
-pe-	20.01	45.02	-4757	5160	0.1211
-pe-	20.02	45.03	-4765	5144	0.1211
-pe-	20.02	45.02	-4774	5138	0.1211
-pe-	20.00	45.01	-4773	5137	0.1211
-pe-	20.00	45.01	-4771	5139	0.1211

Wednesday, August 08, 2012, Time 22:51

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.1184 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.1237 W/mK
Percent Difference: 4.39%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	30.00	55.01	-4717	5519	0.1235
-te-	30.00	55.01	-4795	5444	0.1236
-te-	30.00	55.00	-4845	5371	0.1233
-te-	30.00	55.01	-4867	5393	0.1238
-pe-	30.01	55.04	-4871	5375	0.1235
-pe-	30.01	55.04	-4877	5360	0.1235
-pe-	30.02	55.03	-4885	5329	0.1233

-pe-	30.02	55.03	-4895	5322	0.1233
-pe-	30.01	55.01	-4901	5320	0.1234
-pe-	30.00	55.01	-4901	5316	0.1234

Thursday, August 09, 2012, Time 00:18

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.01 °C
Results Upper: 0.1195 W/mK
Temperature Lower: 55.02 °C
Results Lower: 0.1272 W/mK
Percent Difference: 6.22%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	40.02	65.02	-5081	5522	0.1266
-pe-	40.02	65.02	-5091	5513	0.1266
-pe-	40.02	65.02	-5100	5507	0.1266
-pe-	40.02	65.02	-5108	5498	0.1266
-pe-	40.02	65.02	-5113	5499	0.1267
-pe-	40.01	65.01	-5115	5497	0.1267
-pe-	40.01	65.01	-5116	5496	0.1266
-pe-	40.01	65.01	-5117	5490	0.1266
-pe-	40.01	65.00	-5118	5493	0.1267
-pe-	40.00	65.00	-5117	5501	0.1267

Thursday, August 09, 2012, Time 02:16

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.1229 W/mK
Temperature Lower: 65.00 °C
Results Lower: 0.1305 W/mK
Percent Difference: 6.02%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	50.01	75.02	-5090	5933	0.1301
-te-	50.01	74.99	-5159	5852	0.1300
-te-	50.01	75.02	-5213	5809	0.1301
-te-	50.01	75.01	-5250	5744	0.1298
-te-	50.01	75.01	-5269	5737	0.1299
-pe-	50.02	75.02	-5273	5725	0.1298
-pe-	50.03	75.02	-5283	5718	0.1299
-pe-	50.03	75.02	-5297	5701	0.1299
-pe-	50.02	75.02	-5299	5694	0.1297
-pe-	50.01	75.01	-5297	5695	0.1297

Thursday, August 09, 2012, Time 03:43

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.02 °C
Results Upper: 0.1252 W/mK
Temperature Lower: 75.02 °C
Results Lower: 0.1343 W/mK
Percent Difference: 7.04%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.50	0.1134	0.1108	0.1121
2.50	0.1160	0.1125	0.1143
12.50	0.1170	0.1160	0.1165
22.51	0.1186	0.1194	0.1190
32.51	0.1184	0.1237	0.1211
42.51	0.1195	0.1272	0.1234
52.50	0.1229	0.1305	0.1267
62.52	0.1252	0.1343	0.1298

Polymer Decking Batch001 Sample 2(32)

Thursday, August 09, 2012, Time 13:04

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB001N32
Sample Thickness: 2.503cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-20.03	4.99	-4190	4278	0.1089
-te-	-20.02	4.99	-4181	4316	0.1093
-pe-	-20.02	4.98	-4173	4324	0.1093
-pe-	-20.03	4.97	-4158	4338	0.1093
-pe-	-20.03	4.97	-4145	4352	0.1093
-pe-	-20.02	4.98	-4136	4363	0.1093
-pe-	-20.01	4.98	-4129	4372	0.1094
-pe-	-20.01	4.99	-4126	4378	0.1094
-pe-	-20.00	5.00	-4124	4380	0.1094
-pe-	-20.00	5.00	-4126	4379	0.1094

Thursday, August 09, 2012, Time 13:58

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.00 °C
Results Upper: 0.1102 W/mK
Temperature Lower: 5.00 °C
Results Lower: 0.1086 W/mK
Percent Difference: 1.44%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	-10.00	15.03	-4239	4544	0.1113
-pe-	-10.00	15.02	-4241	4535	0.1113
-pe-	-9.99	15.02	-4246	4528	0.1113
-pe-	-9.99	15.02	-4251	4521	0.1113
-pe-	-10.00	15.01	-4257	4517	0.1113
-pe-	-10.00	15.01	-4260	4514	0.1113
-pe-	-10.00	15.01	-4265	4513	0.1114
-pe-	-10.00	15.01	-4268	4512	0.1114
-pe-	-10.00	15.01	-4268	4512	0.1114
-pe-	-10.01	15.00	-4267	4512	0.1114

Thursday, August 09, 2012, Time 15:51

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.1118 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.1110 W/mK
Percent Difference: 0.67%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-4276	4799	0.1136
-te-	-0.01	25.00	-4313	4751	0.1135
-pe-	0.01	25.01	-4322	4745	0.1135
-pe-	0.02	25.02	-4334	4734	0.1135
-pe-	0.02	25.03	-4345	4722	0.1135
-pe-	0.02	25.03	-4357	4709	0.1135
-pe-	0.01	25.02	-4365	4700	0.1135

-pe-	0.00	25.01	-4369	4695	0.1135
-pe-	-0.00	25.01	-4370	4694	0.1135
-pe-	-0.01	25.00	-4370	4693	0.1135

Thursday, August 09, 2012, Time 17:23

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.1123 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.1147 W/mK
Percent Difference: 2.04%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-4448	4929	0.1159
-te-	10.00	35.01	-4480	4907	0.1160
-pe-	10.02	35.03	-4485	4897	0.1160
-pe-	10.03	35.04	-4497	4882	0.1159
-pe-	10.03	35.05	-4511	4862	0.1159
-pe-	10.02	35.04	-4521	4845	0.1158
-pe-	10.02	35.04	-4529	4831	0.1157
-pe-	10.01	35.03	-4533	4823	0.1157
-pe-	10.01	35.02	-4533	4819	0.1156
-pe-	10.00	35.01	-4531	4819	0.1156

Thursday, August 09, 2012, Time 18:56

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.1144 W/mK
Temperature Lower: 35.02 °C
Results Lower: 0.1169 W/mK
Percent Difference: 2.13%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	20.00	45.01	-4587	5071	0.1179
-pe-	20.02	45.03	-4594	5060	0.1179
-pe-	20.04	45.04	-4609	5045	0.1179
-pe-	20.04	45.05	-4625	5025	0.1178
-pe-	20.03	45.05	-4639	5008	0.1178
-pe-	20.02	45.04	-4647	4993	0.1177
-pe-	20.01	45.03	-4649	4986	0.1176
-pe-	20.01	45.03	-4651	4982	0.1176
-pe-	20.01	45.02	-4651	4977	0.1176
-pe-	20.00	45.01	-4649	4984	0.1177

Thursday, August 09, 2012, Time 20:33

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.00 °C
Results Upper: 0.1153 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.1199 W/mK
Percent Difference: 3.87%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	30.00	55.00	-4643	5300	0.1200
-te-	30.00	55.01	-4684	5266	0.1200
-pe-	30.02	55.04	-4693	5249	0.1199
-pe-	30.04	55.05	-4712	5224	0.1199
-pe-	30.04	55.06	-4731	5196	0.1197
-pe-	30.03	55.05	-4746	5182	0.1197
-pe-	30.02	55.05	-4756	5167	0.1197
-pe-	30.01	55.03	-4763	5153	0.1196
-pe-	30.00	55.02	-4765	5150	0.1196

-pe-	30.00	55.01	-4764	5151	0.1196

Thursday, August 09, 2012, Time 22:05

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.01 °C
Results Upper: 0.1162 W/mK
Temperature Lower: 55.02 °C
Results Lower: 0.1231 W/mK
Percent Difference: 5.80%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	40.03	65.04	-4863	5370	0.1220
-pe-	40.03	65.05	-4878	5352	0.1220
-pe-	40.03	65.04	-4892	5333	0.1220
-pe-	40.03	65.03	-4902	5321	0.1220
-pe-	40.02	65.03	-4910	5315	0.1220
-pe-	40.02	65.01	-4916	5306	0.1220
-pe-	40.01	65.01	-4918	5312	0.1221
-pe-	40.01	65.01	-4921	5305	0.1220
-pe-	40.01	65.01	-4922	5315	0.1222
-pe-	40.00	65.00	-4920	5318	0.1222

Thursday, August 09, 2012, Time 23:58

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.1181 W/mK
Temperature Lower: 65.00 °C
Results Lower: 0.1261 W/mK
Percent Difference: 6.57%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	50.01	75.01	-5052	5543	0.1250
-pe-	50.03	75.02	-5065	5527	0.1250
-pe-	50.04	75.03	-5083	5509	0.1251
-pe-	50.04	75.04	-5098	5506	0.1251
-pe-	50.04	75.04	-5111	5484	0.1250
-pe-	50.03	75.03	-5119	5476	0.1250
-pe-	50.03	75.04	-5125	5478	0.1250
-pe-	50.02	75.02	-5130	5455	0.1249
-pe-	50.01	75.01	-5133	5452	0.1249
-pe-	50.01	75.00	-5132	5455	0.1250

Friday, August 10, 2012, Time 01:41

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.01 °C
Results Upper: 0.1213 W/mK
Temperature Lower: 75.01 °C
Results Lower: 0.1286 W/mK
Percent Difference: 5.87%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.50	0.1102	0.1086	0.1094
2.50	0.1118	0.1110	0.1114
12.50	0.1123	0.1147	0.1135
22.51	0.1144	0.1169	0.1156
32.51	0.1153	0.1199	0.1176
42.51	0.1162	0.1231	0.1196
52.51	0.1181	0.1261	0.1221
62.51	0.1213	0.1286	0.1249

Polymer Decking Batch001 Sample 3(33)

Friday, August 10, 2012, Time 16:05

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB001N33
Sample Thickness: 2.508cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	-19.98	4.99	-4183	4331	0.1099
-pe-	-20.04	4.99	-4197	4335	0.1099
-pe-	-20.04	4.99	-4178	4342	0.1097
-pe-	-20.04	4.98	-4157	4351	0.1096
-pe-	-20.02	4.98	-4138	4362	0.1096
-pe-	-20.02	4.98	-4143	4372	0.1098
-pe-	-20.00	4.99	-4135	4376	0.1097
-pe-	-20.00	4.99	-4138	4378	0.1098
-pe-	-19.99	5.00	-4133	4379	0.1097
-pe-	-19.99	5.00	-4135	4377	0.1097

Friday, August 10, 2012, Time 16:59

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -19.99 °C
Results Upper: 0.1107 W/mK
Temperature Lower: 5.00 °C
Results Lower: 0.1088 W/mK
Percent Difference: 1.69%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-4206	4599	0.1119
-te-	-10.01	15.00	-4233	4563	0.1118
-pe-	-9.99	15.01	-4240	4559	0.1119
-pe-	-9.98	15.03	-4250	4548	0.1118
-pe-	-9.98	15.03	-4263	4534	0.1118
-pe-	-9.99	15.03	-4271	4522	0.1118
-pe-	-10.00	15.02	-4276	4514	0.1117
-pe-	-10.00	15.01	-4279	4510	0.1117
-pe-	-10.00	15.01	-4279	4508	0.1117
-pe-	-10.00	15.00	-4279	4508	0.1117

Friday, August 10, 2012, Time 18:31

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.1123 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.1112 W/mK
Percent Difference: 1.01%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-4337	4741	0.1139
-pe-	0.00	25.01	-4343	4736	0.1139
-pe-	0.02	25.03	-4354	4722	0.1139
-pe-	0.02	25.03	-4366	4707	0.1138
-pe-	0.01	25.03	-4374	4694	0.1137
-pe-	0.01	25.02	-4379	4685	0.1137
-pe-	0.00	25.01	-4383	4679	0.1137

-pe-	-0.00	25.01	-4386	4677	0.1137
-pe-	-0.00	25.00	-4387	4676	0.1137
-pe-	-0.01	25.00	-4387	4676	0.1137

Friday, August 10, 2012, Time 20:09

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.1130 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.1145 W/mK
Percent Difference: 1.28%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-4445	4929	0.1161
-te-	10.00	35.00	-4481	4882	0.1160
-pe-	10.02	35.02	-4488	4876	0.1160
-pe-	10.03	35.04	-4502	4862	0.1160
-pe-	10.03	35.05	-4517	4843	0.1160
-pe-	10.03	35.04	-4530	4825	0.1159
-pe-	10.02	35.04	-4539	4812	0.1158
-pe-	10.01	35.03	-4544	4802	0.1158
-pe-	10.01	35.02	-4547	4798	0.1158
-pe-	10.00	35.01	-4546	4798	0.1158

Friday, August 10, 2012, Time 21:41

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.1150 W/mK
Temperature Lower: 35.02 °C
Results Lower: 0.1166 W/mK
Percent Difference: 1.40%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	20.00	45.01	-4559	5087	0.1180
-te-	20.00	45.01	-4597	5050	0.1181
-pe-	20.02	45.03	-4605	5040	0.1180
-pe-	20.04	45.05	-4622	5022	0.1180
-pe-	20.05	45.06	-4642	5001	0.1180
-pe-	20.04	45.06	-4658	4978	0.1179
-pe-	20.02	45.05	-4668	4961	0.1178
-pe-	20.02	45.03	-4673	4951	0.1178
-pe-	20.01	45.02	-4676	4948	0.1178
-pe-	20.00	45.01	-4676	4952	0.1179

Friday, August 10, 2012, Time 23:13

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.1162 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.1194 W/mK
Percent Difference: 2.72%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	30.00	55.01	-4706	5229	0.1201
-pe-	30.02	55.03	-4716	5209	0.1200
-pe-	30.04	55.05	-4733	5192	0.1200
-pe-	30.04	55.05	-4752	5167	0.1199
-pe-	30.03	55.05	-4767	5152	0.1199
-pe-	30.02	55.04	-4778	5133	0.1198
-pe-	30.01	55.03	-4785	5125	0.1198
-pe-	30.01	55.02	-4788	5122	0.1198
-pe-	30.00	55.01	-4788	5112	0.1197

-pe-	30.00	55.00	-4786	5116	0.1198

Saturday, August 11, 2012, Time 00:51

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.1170 W/mK
Temperature Lower: 55.01 °C
Results Lower: 0.1226 W/mK
Percent Difference: 4.63%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	40.00	65.03	-4845	5415	0.1225
-pe-	40.02	65.05	-4855	5384	0.1223
-pe-	40.05	65.07	-4875	5352	0.1222
-pe-	40.05	65.07	-4897	5327	0.1221
-pe-	40.05	65.07	-4917	5296	0.1220
-pe-	40.03	65.04	-4933	5267	0.1219
-pe-	40.02	65.03	-4942	5257	0.1219
-pe-	40.01	65.02	-4946	5256	0.1220
-pe-	40.01	65.00	-4947	5252	0.1220
-pe-	40.00	65.00	-4944	5262	0.1221

Saturday, August 11, 2012, Time 02:28

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.1190 W/mK
Temperature Lower: 65.01 °C
Results Lower: 0.1251 W/mK
Percent Difference: 5.01%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [μV]	Qlower [μV]	Lambda [W/mK]
-te-	50.00	74.98	-5031	5467	0.1242
-te-	50.01	75.02	-5053	5466	0.1243
-pe-	50.02	75.02	-5055	5467	0.1244
-pe-	50.02	75.04	-5062	5455	0.1243
-pe-	50.02	75.03	-5073	5427	0.1241
-pe-	50.03	75.03	-5081	5419	0.1241
-pe-	50.03	75.03	-5087	5420	0.1242
-pe-	50.02	75.02	-5094	5403	0.1241
-pe-	50.02	75.01	-5097	5399	0.1241
-pe-	50.01	75.00	-5096	5401	0.1242

Saturday, August 11, 2012, Time 04:11

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.02 °C
Results Upper: 0.1207 W/mK
Temperature Lower: 75.01 °C
Results Lower: 0.1276 W/mK
Percent Difference: 5.60%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.50	0.1107	0.1088	0.1097
2.50	0.1123	0.1112	0.1117
12.50	0.1130	0.1145	0.1137
22.51	0.1150	0.1166	0.1158
32.51	0.1162	0.1194	0.1178
42.50	0.1170	0.1226	0.1198
52.51	0.1190	0.1251	0.1220
62.51	0.1207	0.1276	0.1241

Polymer Decking Batch001 Sample 4(40)

Monday, August 20, 2012, Time 10:08

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB001N40
Sample Thickness: 2.511cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	-20.01	4.99	-4217	4197	0.1087
-te-	-20.01	4.99	-4163	4264	0.1088
-te-	-20.01	4.99	-4135	4302	0.1089
-pe-	-20.02	4.98	-4126	4310	0.1088
-pe-	-20.03	4.97	-4114	4323	0.1089
-pe-	-20.03	4.97	-4100	4339	0.1089
-pe-	-20.02	4.97	-4091	4352	0.1089
-pe-	-20.01	4.98	-4085	4361	0.1090
-pe-	-20.01	4.99	-4084	4364	0.1090
-pe-	-20.00	5.00	-4085	4363	0.1090

Monday, August 20, 2012, Time 11:10

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.01 °C
Results Upper: 0.1094 W/mK
Temperature Lower: 4.99 °C
Results Lower: 0.1085 W/mK
Percent Difference: 0.83%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-4111	4622	0.1110
-te-	-10.01	15.00	-4140	4585	0.1110
-pe-	-9.99	15.01	-4144	4581	0.1110
-pe-	-9.98	15.03	-4157	4569	0.1110
-pe-	-9.98	15.03	-4169	4554	0.1109
-pe-	-9.98	15.03	-4178	4541	0.1109
-pe-	-9.99	15.02	-4183	4532	0.1108
-pe-	-10.00	15.01	-4184	4528	0.1108
-pe-	-10.00	15.01	-4185	4526	0.1108
-pe-	-10.01	15.00	-4184	4527	0.1108

Monday, August 20, 2012, Time 12:43

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.1099 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.1117 W/mK
Percent Difference: 1.63%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-4257	4750	0.1131
-te-	-0.01	25.00	-4289	4714	0.1130
-pe-	0.01	25.01	-4296	4708	0.1131
-pe-	0.02	25.03	-4309	4694	0.1130
-pe-	0.02	25.04	-4322	4677	0.1130
-pe-	0.02	25.03	-4334	4661	0.1129
-pe-	0.01	25.03	-4342	4650	0.1129

-pe-	0.00	25.02	-4347	4642	0.1129
-pe-	-0.00	25.01	-4348	4640	0.1129
-pe-	-0.01	25.00	-4346	4642	0.1129

Monday, August 20, 2012, Time 14:15

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.1121 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.1137 W/mK
Percent Difference: 1.44%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-4370	4938	0.1154
-te-	10.00	35.00	-4411	4878	0.1152
-te-	10.00	35.00	-4430	4856	0.1152
-pe-	10.01	35.01	-4434	4854	0.1152
-pe-	10.02	35.02	-4442	4849	0.1152
-pe-	10.02	35.03	-4449	4840	0.1152
-pe-	10.02	35.03	-4455	4831	0.1152
-pe-	10.01	35.02	-4458	4826	0.1151
-pe-	10.01	35.02	-4459	4824	0.1151
-pe-	10.00	35.01	-4459	4823	0.1151

Monday, August 20, 2012, Time 15:47

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.1129 W/mK
Temperature Lower: 35.02 °C
Results Lower: 0.1173 W/mK
Percent Difference: 3.85%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	20.00	45.01	-4570	5011	0.1174
-pe-	20.01	45.02	-4574	5005	0.1173
-pe-	20.02	45.04	-4584	4993	0.1173
-pe-	20.03	45.04	-4594	4980	0.1173
-pe-	20.02	45.04	-4602	4971	0.1172
-pe-	20.02	45.03	-4607	4963	0.1172
-pe-	20.01	45.02	-4609	4959	0.1172
-pe-	20.00	45.02	-4608	4957	0.1172
-pe-	20.00	45.01	-4608	4957	0.1172
-pe-	20.00	45.01	-4607	4958	0.1172

Monday, August 20, 2012, Time 17:30

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.00 °C
Results Upper: 0.1146 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.1197 W/mK
Percent Difference: 4.31%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-pe-	30.01	55.02	-4688	5182	0.1195
-pe-	30.03	55.04	-4700	5169	0.1194
-pe-	30.03	55.04	-4714	5154	0.1194
-pe-	30.03	55.04	-4726	5139	0.1194
-pe-	30.02	55.03	-4735	5126	0.1193
-pe-	30.01	55.03	-4741	5121	0.1194
-pe-	30.01	55.02	-4743	5119	0.1194
-pe-	30.00	55.02	-4743	5116	0.1193
-pe-	30.00	55.01	-4743	5113	0.1193

-pe-	30.00	55.01	-4743	5117	0.1194

Monday, August 20, 2012, Time 19:18

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.1160 W/mK
Temperature Lower: 55.01 °C
Results Lower: 0.1226 W/mK
Percent Difference: 5.55%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	40.00	65.00	-4864	5328	0.1220
-pe-	40.01	65.02	-4867	5320	0.1219
-pe-	40.02	65.03	-4874	5307	0.1218
-pe-	40.02	65.02	-4884	5295	0.1218
-pe-	40.02	65.02	-4894	5284	0.1218
-pe-	40.02	65.01	-4901	5278	0.1219
-pe-	40.02	65.02	-4907	5275	0.1219
-pe-	40.01	65.01	-4909	5275	0.1219
-pe-	40.01	65.01	-4910	5276	0.1219
-pe-	40.01	65.01	-4911	5279	0.1219

Monday, August 20, 2012, Time 21:05

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.1182 W/mK
Temperature Lower: 65.01 °C
Results Lower: 0.1256 W/mK
Percent Difference: 6.12%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	50.01	75.00	-4991	5492	0.1241
-te-	50.00	75.00	-5031	5447	0.1241
-pe-	50.02	75.00	-5037	5453	0.1243
-pe-	50.04	75.02	-5047	5455	0.1244
-pe-	50.04	75.03	-5062	5438	0.1243
-pe-	50.04	75.03	-5075	5427	0.1243
-pe-	50.03	75.04	-5087	5412	0.1242
-pe-	50.03	75.03	-5094	5406	0.1243
-pe-	50.02	75.01	-5107	5364	0.1240
-pe-	50.01	74.98	-5106	5372	0.1241

Monday, August 20, 2012, Time 22:43

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.02 °C
Results Upper: 0.1210 W/mK
Temperature Lower: 75.01 °C
Results Lower: 0.1273 W/mK
Percent Difference: 5.09%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.51	0.1094	0.1085	0.1090
2.50	0.1099	0.1117	0.1108
12.50	0.1121	0.1137	0.1129
22.51	0.1129	0.1173	0.1151
32.51	0.1146	0.1197	0.1172
42.51	0.1160	0.1226	0.1193
52.51	0.1182	0.1256	0.1219
62.51	0.1210	0.1273	0.1241

Polymer Decking Batch002 Sample 1(34)

Monday, August 13, 2012, Time 13:20

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB002N34
Sample Thickness: 2.470cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-20.04	4.99	-3181	3138	0.08021
-te-	-20.01	4.99	-3158	3188	0.08060
-te-	-20.01	5.00	-3132	3218	0.08063
-pe-	-20.01	4.99	-3127	3225	0.08066
-pe-	-20.02	4.98	-3118	3236	0.08069
-pe-	-20.02	4.98	-3111	3245	0.08070
-pe-	-20.02	4.98	-3104	3254	0.08071
-pe-	-20.01	4.99	-3102	3259	0.08075
-pe-	-19.99	5.00	-3099	3260	0.08074
-pe-	-20.00	5.00	-3101	3260	0.08073

Monday, August 13, 2012, Time 14:54

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.00 °C
Results Upper: 0.08171 W/mK
Temperature Lower: 5.00 °C
Results Lower: 0.07977 W/mK
Percent Difference: 2.40%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	-10.01	15.00	-3175	3453	0.08296
-te-	-10.01	15.00	-3211	3407	0.08286
-pe-	-9.98	15.02	-3221	3399	0.08291
-pe-	-9.97	15.04	-3235	3382	0.08287
-pe-	-9.97	15.04	-3252	3363	0.08283
-pe-	-9.98	15.04	-3266	3346	0.08278
-pe-	-10.00	15.03	-3272	3335	0.08274
-pe-	-10.00	15.01	-3272	3331	0.08270
-pe-	-10.00	15.01	-3273	3330	0.08272
-pe-	-10.01	15.00	-3273	3330	0.08273

Monday, August 13, 2012, Time 16:21

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.08458 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.08086 W/mK
Percent Difference: 4.50%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	-0.01	25.00	-3182	3740	0.08543
-te-	-0.01	25.00	-3249	3657	0.08528
-te-	-0.01	25.00	-3285	3613	0.08521
-pe-	0.01	25.02	-3295	3604	0.08523
-pe-	0.03	25.04	-3313	3584	0.08522
-pe-	0.04	25.05	-3332	3561	0.08517
-pe-	0.02	25.04	-3345	3542	0.08508

-pe-	0.01	25.03	-3351	3531	0.08502
-pe-	-0.00	25.01	-3352	3527	0.08502
-pe-	-0.01	25.00	-3350	3527	0.08498

Monday, August 13, 2012, Time 17:43

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.08499 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.08502 W/mK
Percent Difference: 0.04%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-3430	3741	0.08749
-te-	10.00	35.00	-3456	3708	0.08744
-pe-	10.01	35.02	-3462	3704	0.08746
-pe-	10.03	35.03	-3473	3692	0.08745
-pe-	10.03	35.04	-3484	3680	0.08744
-pe-	10.02	35.03	-3492	3669	0.08737
-pe-	10.02	35.03	-3497	3659	0.08732
-pe-	10.01	35.02	-3499	3655	0.08732
-pe-	10.00	35.01	-3498	3654	0.08730
-pe-	10.00	35.00	-3497	3657	0.08734

Monday, August 13, 2012, Time 19:15

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.00 °C
Results Upper: 0.08716 W/mK
Temperature Lower: 35.01 °C
Results Lower: 0.08748 W/mK
Percent Difference: 0.36%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	20.00	45.00	-3462	3973	0.08958
-te-	20.00	45.01	-3526	3921	0.08973
-te-	20.00	45.01	-3563	3881	0.08971
-pe-	20.01	45.02	-3568	3877	0.08973
-pe-	20.01	45.03	-3572	3867	0.08961
-pe-	20.02	45.05	-3582	3849	0.08951
-pe-	20.03	45.04	-3595	3833	0.08952
-pe-	20.03	45.03	-3607	3819	0.08952
-pe-	20.01	45.02	-3609	3813	0.08945
-pe-	19.99	45.01	-3603	3814	0.08938

Monday, August 13, 2012, Time 20:43

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.08827 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.09063 W/mK
Percent Difference: 2.63%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	30.00	55.01	-3577	4169	0.09220
-te-	30.00	55.01	-3622	4109	0.09203
-te-	30.00	55.01	-3648	4072	0.09190
-pe-	30.02	55.02	-3656	4062	0.09191
-pe-	30.03	55.03	-3670	4050	0.09194
-pe-	30.04	55.04	-3688	4034	0.09197
-pe-	30.03	55.05	-3702	4026	0.09199
-pe-	30.02	55.03	-3712	3996	0.09177
-pe-	30.01	55.01	-3717	3989	0.09181

-pe-	30.00	55.02	-3717	4003	0.09192

Monday, August 13, 2012, Time 22:10

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.01 °C
Results Upper: 0.08942 W/mK
Temperature Lower: 55.02 °C
Results Lower: 0.09425 W/mK
Percent Difference: 5.26%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	40.00	64.99	-3764	4286	0.09483
-te-	40.00	65.01	-3805	4214	0.09438
-te-	40.00	65.01	-3824	4222	0.09473
-pe-	40.02	65.04	-3830	4207	0.09456
-pe-	40.02	65.05	-3838	4195	0.09450
-pe-	40.02	65.04	-3848	4175	0.09440
-pe-	40.02	65.04	-3857	4164	0.09439
-pe-	40.02	65.02	-3864	4148	0.09433
-pe-	40.01	65.02	-3868	4145	0.09434
-pe-	40.00	65.01	-3867	4149	0.09437

Monday, August 13, 2012, Time 23:42

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.09155 W/mK
Temperature Lower: 65.02 °C
Results Lower: 0.09714 W/mK
Percent Difference: 5.92%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	50.01	74.99	-3981	4349	0.09704
-pe-	50.02	75.02	-3985	4340	0.09692
-pe-	50.03	75.04	-3992	4330	0.09685
-pe-	50.03	75.04	-4005	4301	0.09669
-pe-	50.02	75.02	-4011	4293	0.09671
-pe-	50.02	75.01	-4017	4284	0.09668
-pe-	50.02	75.01	-4017	4289	0.09674
-pe-	50.01	75.01	-4018	4289	0.09673
-pe-	50.01	75.01	-4019	4285	0.09669
-pe-	50.01	75.01	-4017	4287	0.09670

Tuesday, August 14, 2012, Time 01:25

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.01 °C
Results Upper: 0.09368 W/mK
Temperature Lower: 75.01 °C
Results Lower: 0.09973 W/mK
Percent Difference: 6.27%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.50	0.08171	0.07977	0.08074
2.50	0.08458	0.08086	0.08272
12.51	0.08499	0.08502	0.08501
22.51	0.08716	0.08748	0.08732
32.52	0.08827	0.09063	0.08945
42.52	0.08942	0.09425	0.09183
52.52	0.09155	0.09714	0.09435
62.51	0.09368	0.09973	0.09671

Polymer Decking Batch002 Sample 2(35)

Tuesday, August 14, 2012, Time 12:53

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB002N35
Sample Thickness: 2.485cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-ne-	-19.91	5.00	-3050	3013	0.07781
-pe-	-20.03	4.99	-3075	3016	0.07784
-pe-	-20.07	4.97	-3045	3028	0.07749
-pe-	-20.05	4.97	-3022	3043	0.07744
-pe-	-20.03	4.97	-3007	3058	0.07749
-pe-	-20.01	4.98	-3000	3068	0.07755
-pe-	-20.01	4.99	-2999	3074	0.07760
-pe-	-20.01	4.99	-2999	3076	0.07761
-pe-	-20.01	4.99	-2996	3080	0.07760
-pe-	-20.01	4.99	-2997	3079	0.07760

Tuesday, August 14, 2012, Time 13:53

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.01 °C
Results Upper: 0.07945 W/mK
Temperature Lower: 4.99 °C
Results Lower: 0.07576 W/mK
Percent Difference: 4.74%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-2972	3362	0.07970
-te-	-10.01	15.00	-3009	3317	0.07962
-pe-	-9.98	15.03	-3022	3307	0.07969
-pe-	-9.96	15.05	-3043	3286	0.07968
-pe-	-9.97	15.05	-3060	3263	0.07960
-pe-	-9.98	15.04	-3072	3244	0.07951
-pe-	-9.99	15.03	-3078	3232	0.07945
-pe-	-10.00	15.02	-3081	3226	0.07943
-pe-	-10.00	15.01	-3082	3225	0.07946
-pe-	-10.01	15.00	-3082	3228	0.07949

Tuesday, August 14, 2012, Time 15:20

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.08012 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.07880 W/mK
Percent Difference: 1.66%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-3118	3459	0.08173
-te-	-0.01	25.00	-3142	3433	0.08170
-pe-	0.00	25.01	-3148	3428	0.08173
-pe-	0.02	25.03	-3159	3416	0.08171
-pe-	0.01	25.03	-3169	3402	0.08166
-pe-	0.01	25.02	-3176	3391	0.08161
-pe-	0.00	25.02	-3180	3384	0.08158

-pe-	-0.00	25.01	-3181	3381	0.08156
-pe-	-0.00	25.01	-3182	3380	0.08157
-pe-	-0.01	25.00	-3181	3380	0.08156

Tuesday, August 14, 2012, Time 16:52

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.08118 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.08195 W/mK
Percent Difference: 0.94%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-3202	3651	0.08407
-te-	10.00	35.01	-3245	3602	0.08402
-pe-	10.03	35.03	-3256	3592	0.08405
-pe-	10.04	35.05	-3275	3567	0.08396
-pe-	10.04	35.06	-3293	3542	0.08386
-pe-	10.03	35.05	-3306	3521	0.08376
-pe-	10.02	35.04	-3313	3508	0.08370
-pe-	10.01	35.02	-3316	3501	0.08367
-pe-	10.01	35.01	-3317	3501	0.08370
-pe-	10.00	35.01	-3316	3502	0.08371

Tuesday, August 14, 2012, Time 18:20

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.08311 W/mK
Temperature Lower: 35.01 °C
Results Lower: 0.08428 W/mK
Percent Difference: 1.40%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	20.00	45.01	-3226	3908	0.08641
-te-	20.00	45.00	-3303	3783	0.08591
-te-	20.00	45.02	-3349	3763	0.08615
-pe-	20.03	45.04	-3361	3743	0.08608
-pe-	20.05	45.07	-3382	3716	0.08598
-pe-	20.04	45.07	-3401	3690	0.08589
-pe-	20.03	45.06	-3415	3666	0.08579
-pe-	20.02	45.04	-3423	3648	0.08569
-pe-	20.01	45.02	-3426	3641	0.08568
-pe-	20.00	45.01	-3426	3643	0.08572

Tuesday, August 14, 2012, Time 19:42

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.08432 W/mK
Temperature Lower: 45.03 °C
Results Lower: 0.08707 W/mK
Percent Difference: 3.20%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	30.00	55.01	-3509	3842	0.08803
-pe-	30.01	55.02	-3515	3826	0.08793
-pe-	30.02	55.03	-3523	3815	0.08791
-pe-	30.02	55.03	-3531	3817	0.08800
-pe-	30.02	55.04	-3539	3804	0.08793
-pe-	30.01	55.03	-3545	3796	0.08792
-pe-	30.01	55.03	-3548	3790	0.08788
-pe-	30.01	55.01	-3552	3783	0.08788
-pe-	30.00	55.01	-3552	3787	0.08793

-pe-	30.00	55.01	-3552	3789	0.08796

Tuesday, August 14, 2012, Time 21:24

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.08600 W/mK
Temperature Lower: 55.01 °C
Results Lower: 0.08985 W/mK
Percent Difference: 4.38%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	40.02	65.03	-3633	3989	0.09028
-pe-	40.04	65.03	-3650	3963	0.09021
-pe-	40.04	65.04	-3664	3959	0.09027
-pe-	40.03	65.04	-3674	3945	0.09021
-pe-	40.02	65.04	-3682	3928	0.09007
-pe-	40.01	65.02	-3685	3917	0.09004
-pe-	40.01	65.02	-3686	3922	0.09010
-pe-	40.01	65.01	-3687	3915	0.09005
-pe-	40.00	65.00	-3688	3911	0.09003
-pe-	40.00	65.00	-3685	3923	0.09014

Tuesday, August 14, 2012, Time 23:07

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.00 °C
Results Upper: 0.08784 W/mK
Temperature Lower: 65.00 °C
Results Lower: 0.09230 W/mK
Percent Difference: 4.96%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	50.01	75.00	-3768	4125	0.09250
-pe-	50.04	75.05	-3780	4111	0.09238
-pe-	50.05	75.05	-3798	4088	0.09234
-pe-	50.04	75.05	-3814	4065	0.09226
-pe-	50.03	75.04	-3827	4045	0.09216
-pe-	50.03	75.03	-3834	4035	0.09215
-pe-	50.02	75.02	-3838	4029	0.09215
-pe-	50.01	75.01	-3839	4024	0.09210
-pe-	50.00	74.98	-3843	4004	0.09199
-pe-	50.00	74.98	-3838	4021	0.09214

Wednesday, August 15, 2012, Time 00:44

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.00 °C
Results Upper: 0.09011 W/mK
Temperature Lower: 74.99 °C
Results Lower: 0.09405 W/mK
Percent Difference: 4.27%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.51	0.07945	0.07576	0.07760
2.50	0.08012	0.07880	0.07946
12.50	0.08118	0.08195	0.08156
22.51	0.08311	0.08428	0.08369
32.52	0.08432	0.08707	0.08570
42.51	0.08600	0.08985	0.08792
52.50	0.08784	0.09230	0.09007
62.50	0.09011	0.09405	0.09208

Polymer Decking Batch002 Sample 3(36)

Wednesday, August 15, 2012, Time 12:46

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB002N36
Sample Thickness: 2.475cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	-20.01	4.99	-3152	3153	0.08024
-te-	-20.01	5.00	-3115	3202	0.08036
-te-	-20.01	4.99	-3092	3228	0.08036
-pe-	-20.02	4.98	-3086	3234	0.08036
-pe-	-20.03	4.97	-3073	3247	0.08037
-pe-	-20.03	4.97	-3064	3261	0.08043
-pe-	-20.02	4.97	-3055	3273	0.08046
-pe-	-20.01	4.98	-3050	3281	0.08048
-pe-	-20.00	4.99	-3049	3284	0.08052
-pe-	-20.00	5.00	-3052	3282	0.08050

Wednesday, August 15, 2012, Time 14:01

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.01 °C
Results Upper: 0.08053 W/mK
Temperature Lower: 4.99 °C
Results Lower: 0.08047 W/mK
Percent Difference: 0.08%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-3077	3505	0.08247
-pe-	-9.99	15.02	-3087	3498	0.08252
-pe-	-9.97	15.04	-3101	3482	0.08249
-pe-	-9.98	15.04	-3115	3465	0.08244
-pe-	-9.98	15.03	-3122	3451	0.08237
-pe-	-9.99	15.02	-3128	3442	0.08234
-pe-	-10.00	15.01	-3131	3437	0.08233
-pe-	-10.00	15.01	-3132	3436	0.08233
-pe-	-10.00	15.00	-3132	3435	0.08232
-pe-	-10.01	15.00	-3130	3437	0.08234

Wednesday, August 15, 2012, Time 15:33

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.08107 W/mK
Temperature Lower: 15.00 °C
Results Lower: 0.08358 W/mK
Percent Difference: 3.05%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-3215	3641	0.08481
-te-	-0.01	25.00	-3257	3592	0.08475
-pe-	0.00	25.01	-3262	3587	0.08476
-pe-	0.03	25.04	-3278	3570	0.08474
-pe-	0.03	25.05	-3294	3550	0.08469
-pe-	0.02	25.04	-3306	3533	0.08461
-pe-	0.01	25.03	-3312	3520	0.08454

-pe-	-0.00	25.02	-3314	3514	0.08452
-pe-	-0.00	25.01	-3315	3513	0.08453
-pe-	-0.01	25.00	-3315	3513	0.08454

Wednesday, August 15, 2012, Time 17:00

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.08423 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.08483 W/mK
Percent Difference: 0.71%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-3265	3886	0.08734
-te-	10.00	35.00	-3335	3797	0.08716
-te-	10.00	35.01	-3377	3755	0.08715
-pe-	10.02	35.03	-3386	3744	0.08713
-pe-	10.04	35.05	-3403	3724	0.08711
-pe-	10.04	35.06	-3420	3701	0.08701
-pe-	10.03	35.05	-3431	3681	0.08689
-pe-	10.02	35.04	-3439	3668	0.08685
-pe-	10.01	35.02	-3442	3661	0.08683
-pe-	10.00	35.01	-3442	3661	0.08684

Wednesday, August 15, 2012, Time 18:22

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.08587 W/mK
Temperature Lower: 35.02 °C
Results Lower: 0.08781 W/mK
Percent Difference: 2.24%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	20.01	45.02	-3518	3851	0.08898
-pe-	20.02	45.03	-3526	3842	0.08894
-pe-	20.02	45.04	-3535	3827	0.08886
-pe-	20.02	45.03	-3541	3819	0.08884
-pe-	20.02	45.03	-3547	3811	0.08881
-pe-	20.01	45.02	-3547	3807	0.08877
-pe-	20.01	45.02	-3549	3804	0.08878
-pe-	20.01	45.02	-3549	3803	0.08876
-pe-	20.01	45.01	-3550	3802	0.08878
-pe-	20.00	45.01	-3550	3804	0.08880

Wednesday, August 15, 2012, Time 20:05

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.08705 W/mK
Temperature Lower: 45.01 °C
Results Lower: 0.09051 W/mK
Percent Difference: 3.89%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	30.00	55.00	-3506	4127	0.09105
-te-	30.00	55.00	-3556	4093	0.09124
-te-	30.00	55.01	-3589	4050	0.09112
-pe-	30.01	55.03	-3594	4046	0.09110
-pe-	30.03	55.04	-3607	4030	0.09106
-pe-	30.03	55.04	-3623	4009	0.09103
-pe-	30.02	55.04	-3634	3995	0.09100
-pe-	30.01	55.03	-3641	3987	0.09097
-pe-	30.00	55.02	-3641	3986	0.09096

-pe-	30.00	55.02	-3639	3990	0.09097

Wednesday, August 15, 2012, Time 21:32

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.08774 W/mK
Temperature Lower: 55.02 °C
Results Lower: 0.09420 W/mK
Percent Difference: 7.10%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	40.00	65.00	-3669	4282	0.09380
-te-	40.00	65.02	-3719	4231	0.09370
-te-	40.00	65.02	-3757	4164	0.09339
-te-	40.00	64.98	-3776	4143	0.09348
-pe-	40.02	65.02	-3781	4143	0.09348
-pe-	40.02	65.02	-3790	4136	0.09352
-pe-	40.03	65.03	-3800	4130	0.09352
-pe-	40.02	65.02	-3807	4117	0.09346
-pe-	40.01	65.02	-3810	4107	0.09337
-pe-	40.00	65.00	-3807	4111	0.09341

Wednesday, August 15, 2012, Time 22:59

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.09034 W/mK
Temperature Lower: 65.01 °C
Results Lower: 0.09648 W/mK
Percent Difference: 6.58%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	50.00	74.97	-3904	4304	0.09587
-pe-	50.03	75.03	-3913	4297	0.09574
-pe-	50.04	75.05	-3929	4277	0.09567
-pe-	50.04	75.04	-3943	4255	0.09561
-pe-	50.03	75.04	-3953	4243	0.09558
-pe-	50.03	75.03	-3959	4236	0.09557
-pe-	50.02	75.03	-3966	4223	0.09549
-pe-	50.01	75.01	-3968	4218	0.09549
-pe-	50.01	75.01	-3967	4216	0.09547
-pe-	50.01	75.00	-3967	4216	0.09550

Thursday, August 16, 2012, Time 00:37

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.01 °C
Results Upper: 0.09269 W/mK
Temperature Lower: 75.01 °C
Results Lower: 0.09829 W/mK
Percent Difference: 5.86%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.51	0.08053	0.08047	0.08050
2.50	0.08107	0.08358	0.08233
12.50	0.08423	0.08483	0.08453
22.52	0.08587	0.08781	0.08684
32.51	0.08705	0.09051	0.08878
42.51	0.08774	0.09420	0.09097
52.51	0.09034	0.09648	0.09341
62.51	0.09269	0.09829	0.09549

Polymer Decking Batch002 Sample 4(41)

Thursday, August 16, 2012, Time 13:10

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB002N41
Sample Thickness: 2.470cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	-20.03	4.97	-3039	3125	0.07830
-pe-	-20.02	4.97	-3034	3135	0.07835
-pe-	-20.01	4.99	-3031	3140	0.07838
-pe-	-20.01	4.99	-3029	3144	0.07838
-pe-	-20.01	5.00	-3027	3146	0.07837
-pe-	-20.01	5.00	-3023	3147	0.07831
-pe-	-20.01	5.00	-3020	3149	0.07830
-pe-	-20.00	5.00	-3020	3149	0.07832
-pe-	-20.00	5.00	-3019	3150	0.07833
-pe-	-20.00	5.00	-3020	3150	0.07832

Thursday, August 16, 2012, Time 14:28

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.00 °C
Results Upper: 0.07957 W/mK
Temperature Lower: 5.00 °C
Results Lower: 0.07707 W/mK
Percent Difference: 3.19%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-3090	3314	0.08016
-pe-	-10.00	15.01	-3093	3310	0.08016
-pe-	-9.99	15.02	-3100	3302	0.08014
-pe-	-9.99	15.03	-3111	3290	0.08013
-pe-	-9.99	15.03	-3119	3279	0.08009
-pe-	-10.00	15.02	-3123	3272	0.08005
-pe-	-10.00	15.01	-3123	3269	0.08004
-pe-	-10.00	15.01	-3124	3268	0.08004
-pe-	-10.00	15.00	-3125	3269	0.08007
-pe-	-10.01	15.00	-3121	3273	0.08008

Thursday, August 16, 2012, Time 16:05

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.01 °C
Results Upper: 0.08073 W/mK
Temperature Lower: 15.00 °C
Results Lower: 0.07941 W/mK
Percent Difference: 1.65%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-3110	3556	0.08231
-te-	-0.01	25.00	-3150	3507	0.08223
-pe-	0.01	25.02	-3159	3499	0.08224
-pe-	0.03	25.04	-3176	3480	0.08222
-pe-	0.03	25.05	-3193	3459	0.08215
-pe-	0.02	25.04	-3204	3441	0.08207
-pe-	0.01	25.03	-3211	3429	0.08202

-pe-	0.00	25.02	-3215	3423	0.08201
-pe-	-0.00	25.01	-3216	3421	0.08202
-pe-	-0.01	25.00	-3216	3422	0.08204

Thursday, August 16, 2012, Time 17:32

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.00 °C
Results Upper: 0.08157 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.08248 W/mK
Percent Difference: 1.11%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-3264	3650	0.08435
-te-	10.00	35.00	-3290	3621	0.08433
-pe-	10.02	35.02	-3296	3616	0.08433
-pe-	10.03	35.03	-3307	3605	0.08433
-pe-	10.03	35.04	-3318	3591	0.08428
-pe-	10.02	35.04	-3325	3577	0.08419
-pe-	10.01	35.03	-3329	3569	0.08415
-pe-	10.01	35.02	-3330	3565	0.08413
-pe-	10.00	35.01	-3330	3563	0.08411
-pe-	10.00	35.00	-3328	3565	0.08413

Thursday, August 16, 2012, Time 19:05

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.00 °C
Results Upper: 0.08294 W/mK
Temperature Lower: 35.01 °C
Results Lower: 0.08530 W/mK
Percent Difference: 2.80%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	20.00	45.01	-3342	3838	0.08648
-te-	20.00	45.02	-3389	3795	0.08653
-pe-	20.03	45.04	-3399	3778	0.08647
-pe-	20.04	45.06	-3417	3754	0.08639
-pe-	20.04	45.06	-3435	3728	0.08628
-pe-	20.03	45.05	-3447	3707	0.08619
-pe-	20.02	45.03	-3456	3696	0.08619
-pe-	20.01	45.02	-3460	3691	0.08619
-pe-	20.01	45.02	-3462	3687	0.08616
-pe-	20.00	45.01	-3462	3689	0.08620

Thursday, August 16, 2012, Time 20:32

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.08472 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.08764 W/mK
Percent Difference: 3.38%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	30.00	55.02	-3513	3922	0.08849
-pe-	30.02	55.03	-3521	3905	0.08840
-pe-	30.03	55.05	-3537	3890	0.08840
-pe-	30.03	55.05	-3552	3868	0.08833
-pe-	30.03	55.05	-3565	3854	0.08830
-pe-	30.02	55.04	-3573	3839	0.08825
-pe-	30.01	55.02	-3575	3838	0.08825
-pe-	30.01	55.02	-3577	3834	0.08826
-pe-	30.00	55.01	-3578	3824	0.08818

-pe-	30.00	54.99	-3578	3833	0.08833

Thursday, August 16, 2012, Time 22:09

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.08613 W/mK
Temperature Lower: 55.01 °C
Results Lower: 0.09038 W/mK
Percent Difference: 4.81%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	40.00	65.01	-3578	4153	0.09097
-te-	40.00	65.01	-3638	4050	0.09050
-te-	40.00	65.02	-3668	4087	0.09124
-pe-	40.02	65.08	-3678	4047	0.09077
-pe-	40.04	65.07	-3695	3998	0.09046
-te-	40.00	65.01	-3730	3933	0.09023
-te-	40.00	65.01	-3727	3965	0.09053
-pe-	40.00	65.01	-3724	3970	0.09056
-pe-	40.00	65.01	-3725	3961	0.09049
-pe-	40.01	65.01	-3725	3960	0.09049

Thursday, August 16, 2012, Time 23:37

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.00 °C
Results Upper: 0.08819 W/mK
Temperature Lower: 65.01 °C
Results Lower: 0.09284 W/mK
Percent Difference: 5.13%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [μV]	Qlower [μV]	Lambda [W/mK]
-te-	50.01	75.00	-3714	4231	0.09253
-te-	49.99	74.94	-3782	4134	0.09237
-te-	50.01	75.01	-3802	4188	0.09302
-te-	50.00	74.99	-3841	4051	0.09194
-te-	50.01	75.00	-3841	4141	0.09300
-te-	50.01	75.02	-3859	4070	0.09228
-te-	50.01	75.00	-3858	4093	0.09264
-pe-	50.02	75.03	-3861	4087	0.09250
-pe-	50.02	75.03	-3866	4074	0.09243
-pe-	50.01	75.01	-3870	4059	0.09235

Friday, August 17, 2012, Time 01:04

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.02 °C
Results Upper: 0.09012 W/mK
Temperature Lower: 75.02 °C
Results Lower: 0.09474 W/mK
Percent Difference: 5.00%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.50	0.07957	0.07707	0.07832
2.50	0.08073	0.07941	0.08007
12.50	0.08157	0.08248	0.08202
22.51	0.08294	0.08530	0.08412
32.51	0.08472	0.08764	0.08618
42.50	0.08613	0.09038	0.08826
52.51	0.08819	0.09284	0.09052
62.52	0.09012	0.09474	0.09243

Polymer Decking Batch003 Sample 1(37) SET POINT NOT REACHED

Tuesday, August 21, 2012, Time 11:34

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB003N37
Sample Thickness: 2.459cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

****Tuesday, August 21, 2012, Time 13:14

**** Setpoint not reached - setpoint skipped ****

Block Averages for setpoint 1 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-te-	-19.60	5.03	-3133	3369	0.08333
-ne-	-18.86	5.00	-2921	3360	0.08294
-ne-	-18.57	5.00	-2983	3344	0.08461
-ne-	-18.14	5.00	-2826	3314	0.08352
-ne-	-17.47	4.99	-2717	3264	0.08373
-ne-	-17.48	4.99	-2903	3214	0.08573
-ne-	-17.56	4.99	-2971	3166	0.08577
-ne-	-17.57	5.00	-2944	3138	0.08492
-ne-	-17.48	4.99	-2953	3120	0.08519
-ne-	-17.58	4.99	-3030	3112	0.08581

Tuesday, August 21, 2012, Time 13:14

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -17.54 °C
Results Upper: 0.08620 W/mK
Temperature Lower: 4.99 °C
Results Lower: 0.08441 W/mK

Percent Difference: 2.10%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-3344	3642	0.08706
-te-	-10.01	15.00	-3375	3604	0.08698
-pe-	-9.99	15.02	-3382	3597	0.08700
-pe-	-9.98	15.04	-3396	3581	0.08697
-pe-	-9.98	15.04	-3409	3564	0.08692
-pe-	-9.99	15.03	-3418	3550	0.08686
-pe-	-9.99	15.02	-3423	3541	0.08682
-pe-	-10.00	15.01	-3427	3536	0.08682
-pe-	-10.00	15.01	-3427	3535	0.08681
-pe-	-10.00	15.00	-3425	3536	0.08681

Tuesday, August 21, 2012, Time 14:46

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.08816 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.08547 W/mK
Percent Difference: 3.11%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.02	24.99	-3298	4013	0.08979
-te-	-0.02	25.00	-3385	3903	0.08957
-te-	-0.00	25.00	-3430	3854	0.08957
-pe-	0.02	25.04	-3444	3834	0.08946

-pe-	0.05	25.07	-3472	3801	0.08940
-pe-	0.04	25.07	-3502	3762	0.08930
-pe-	0.02	25.05	-3522	3731	0.08916
-pe-	0.00	25.03	-3531	3714	0.08910
-pe-	-0.01	25.01	-3529	3712	0.08907
-pe-	-0.01	25.00	-3525	3715	0.08909

Tuesday, August 21, 2012, Time 16:09

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.01 °C
Results Upper: 0.08908 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.08909 W/mK
Percent Difference: 0.01%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.00	-3550	4021	0.09194
-te-	10.00	35.00	-3584	3976	0.09183
-pe-	10.02	35.02	-3594	3966	0.09185
-pe-	10.04	35.05	-3613	3949	0.09185
-pe-	10.04	35.06	-3630	3925	0.09175
-pe-	10.03	35.06	-3645	3900	0.09161
-pe-	10.03	35.05	-3655	3883	0.09155
-pe-	10.01	35.03	-3660	3874	0.09152
-pe-	10.00	35.01	-3661	3871	0.09151
-pe-	10.00	35.01	-3660	3872	0.09153

Tuesday, August 21, 2012, Time 17:41

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.09079 W/mK
Temperature Lower: 35.02 °C
Results Lower: 0.09225 W/mK
Percent Difference: 1.60%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	20.00	45.01	-3714	4119	0.09396
-te-	20.00	45.01	-3737	4097	0.09399
-pe-	20.02	45.03	-3744	4087	0.09393
-pe-	20.03	45.04	-3756	4072	0.09391
-pe-	20.03	45.04	-3766	4058	0.09386
-pe-	20.03	45.05	-3777	4043	0.09379
-pe-	20.03	45.04	-3788	4028	0.09377
-pe-	20.02	45.03	-3795	4015	0.09372
-pe-	20.01	45.02	-3798	4011	0.09373
-pe-	20.00	45.01	-3798	4014	0.09376

Tuesday, August 21, 2012, Time 19:18

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.09254 W/mK
Temperature Lower: 45.02 °C
Results Lower: 0.09493 W/mK
Percent Difference: 2.54%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.01	55.03	-3868	4257	0.09632
-pe-	30.03	55.04	-3881	4242	0.09629
-pe-	30.03	55.04	-3894	4229	0.09630
-pe-	30.02	55.04	-3906	4215	0.09625
-pe-	30.02	55.03	-3914	4197	0.09615
-pe-	30.02	55.02	-3921	4190	0.09620

-pe-	30.01	55.01	-3924	4192	0.09625
-pe-	30.01	55.01	-3927	4191	0.09627
-pe-	30.00	55.01	-3928	4189	0.09626
-pe-	30.00	55.01	-3928	4191	0.09628

Tuesday, August 21, 2012, Time 21:06

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.09413 W/mK
Temperature Lower: 55.01 °C
Results Lower: 0.09841 W/mK
Percent Difference: 4.46%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	40.00	65.02	-3951	4517	0.09920
-te-	40.00	64.99	-3995	4477	0.09935
-pe-	40.03	65.06	-4007	4453	0.09904
-pe-	40.05	65.07	-4030	4422	0.09900
-pe-	40.05	65.07	-4051	4390	0.09888
-pe-	40.04	65.06	-4070	4365	0.09882
-pe-	40.03	65.04	-4083	4348	0.09879
-pe-	40.02	65.03	-4089	4335	0.09874
-pe-	40.01	65.02	-4091	4331	0.09871
-pe-	40.00	65.00	-4090	4330	0.09873

Tuesday, August 21, 2012, Time 22:38

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.09643 W/mK
Temperature Lower: 65.02 °C
Results Lower: 0.1010 W/mK
Percent Difference: 4.66%

Experiment's Criteria:

Temperature Equilibrium:	0.20
Between Block HFM Equil.:	49
HFM Percent Change:	2.00
Min Number of Blocks:	4
Calculation Blocks:	3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	50.01	75.01	-4107	4637	0.1014
-te-	50.01	75.00	-4159	4564	0.1012
-te-	50.00	74.96	-4198	4505	0.1010
-te-	50.01	75.02	-4204	4546	0.1014
-pe-	50.02	75.04	-4212	4526	0.1012
-pe-	50.03	75.04	-4225	4496	0.1010
-pe-	50.03	75.03	-4237	4471	0.1010
-pe-	50.02	75.01	-4246	4459	0.1010
-pe-	50.02	75.00	-4249	4455	0.1010
-pe-	50.01	75.00	-4249	4460	0.1010

Wednesday, August 22, 2012, Time 00:11

Setpoint No. 8

Setpoint Upper:	50.00 °C
Setpoint Lower:	75.00 °C
Temperature Upper:	50.02 °C
Results Upper:	0.09867 W/mK
Temperature Lower:	75.00 °C
Results Lower:	0.1033 W/mK
Percent Difference:	4.61%

Experiment's Criteria:

Temperature Equilibrium:	0.20
Between Block HFM Equil.:	49
HFM Percent Change:	2.00
Min Number of Blocks:	4
Calculation Blocks:	3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-6.27	0.08620	0.08441	0.08531
2.50	0.08816	0.08547	0.08682
12.50	0.08908	0.08909	0.08909
22.51	0.09079	0.09225	0.09152
32.52	0.09254	0.09493	0.09374
42.51	0.09413	0.09841	0.09627
52.51	0.09643	0.1010	0.09873
62.51	0.09867	0.1033	0.1010

Polymer Decking Batch003 Sample 1(37)

Thursday, August 23, 2012, Time 16:07

WinTherm32 Version 2.18
Instrument Program Version 28
Instrument Serial Number: 185

Sample Name: PolDeckingB003N37
Sample Thickness: 2.456cm
Sample Thickness obtained : from instrument

TEST RUN

Calibration used : 1450b
Calibration read from instrument

Number of transducers per plate: 1
Number of transducers used per plate: 1

Number of Setpoints: 8

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-20.01	4.99	-3270	3258	0.08247
-pe-	-20.03	4.98	-3257	3269	0.08242
-pe-	-20.03	4.97	-3243	3286	0.08246
-pe-	-20.03	4.97	-3229	3302	0.08249
-pe-	-20.02	4.97	-3220	3315	0.08254
-pe-	-20.02	4.98	-3213	3326	0.08258
-pe-	-20.01	4.99	-3209	3333	0.08260
-pe-	-20.01	4.99	-3206	3337	0.08260
-pe-	-20.01	5.00	-3204	3339	0.08259
-pe-	-20.00	5.00	-3204	3338	0.08259

Thursday, August 23, 2012, Time 16:54

Setpoint No. 1
Setpoint Upper: -20.00 °C
Setpoint Lower: 4.99 °C
Temperature Upper: -20.01 °C
Results Upper: 0.08398 W/mK
Temperature Lower: 5.00 °C
Results Lower: 0.08121 W/mK
Percent Difference: 3.35%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 2 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-10.01	15.00	-3252	3557	0.08472
-pe-	-10.00	15.02	-3258	3550	0.08470
-pe-	-9.98	15.03	-3270	3535	0.08468
-pe-	-9.98	15.04	-3282	3519	0.08464
-pe-	-9.98	15.03	-3293	3505	0.08460
-pe-	-9.99	15.03	-3300	3494	0.08456
-pe-	-9.99	15.02	-3305	3487	0.08454
-pe-	-10.00	15.01	-3307	3483	0.08453
-pe-	-10.00	15.01	-3308	3481	0.08453
-pe-	-10.00	15.00	-3308	3481	0.08454

Thursday, August 23, 2012, Time 18:24

Setpoint No. 2
Setpoint Upper: -10.00 °C
Setpoint Lower: 15.00 °C
Temperature Upper: -10.00 °C
Results Upper: 0.08500 W/mK
Temperature Lower: 15.01 °C
Results Lower: 0.08406 W/mK
Percent Difference: 1.11%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 3 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	-0.01	25.00	-3365	3696	0.08673
-pe-	0.01	25.01	-3371	3689	0.08674
-pe-	0.02	25.03	-3386	3675	0.08673
-pe-	0.03	25.04	-3400	3657	0.08669
-pe-	0.02	25.04	-3412	3641	0.08665
-pe-	0.01	25.03	-3421	3628	0.08660
-pe-	0.01	25.02	-3427	3619	0.08658

-pe-	-0.00	25.01	-3430	3615	0.08656
-pe-	-0.01	25.01	-3431	3613	0.08655
-pe-	-0.01	25.00	-3429	3613	0.08655

Thursday, August 23, 2012, Time 19:54

Setpoint No. 3
Setpoint Upper: 0.00 °C
Setpoint Lower: 24.99 °C
Temperature Upper: -0.01 °C
Results Upper: 0.08651 W/mK
Temperature Lower: 25.01 °C
Results Lower: 0.08660 W/mK
Percent Difference: 0.10%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 4 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-te-	10.00	35.01	-3491	3836	0.08888
-pe-	10.02	35.03	-3499	3826	0.08886
-pe-	10.04	35.05	-3515	3809	0.08885
-pe-	10.04	35.05	-3532	3787	0.08878
-pe-	10.03	35.05	-3545	3767	0.08871
-pe-	10.02	35.04	-3555	3754	0.08867
-pe-	10.02	35.03	-3562	3744	0.08866
-pe-	10.01	35.02	-3566	3739	0.08866
-pe-	10.01	35.01	-3568	3737	0.08866
-pe-	10.00	35.01	-3568	3737	0.08867

Thursday, August 23, 2012, Time 21:24

Setpoint No. 4
Setpoint Upper: 9.99 °C
Setpoint Lower: 35.00 °C
Temperature Upper: 10.01 °C
Results Upper: 0.08838 W/mK
Temperature Lower: 35.01 °C
Results Lower: 0.08894 W/mK
Percent Difference: 0.63%

Experiment's Criteria:
Temperature Equilibrium: 0.20

Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 5 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-pe-	20.02	45.02	-3644	3953	0.09106
-pe-	20.04	45.05	-3661	3942	0.09111
-pe-	20.04	45.06	-3679	3917	0.09100
-pe-	20.03	45.06	-3694	3896	0.09092
-pe-	20.03	45.05	-3704	3880	0.09087
-pe-	20.02	45.04	-3711	3866	0.09080
-pe-	20.01	45.03	-3715	3874	0.09093
-pe-	20.01	45.03	-3717	3867	0.09086
-pe-	20.01	45.03	-3719	3863	0.09084
-pe-	20.00	45.02	-3718	3861	0.09083

Thursday, August 23, 2012, Time 22:58

Setpoint No. 5
Setpoint Upper: 20.00 °C
Setpoint Lower: 45.00 °C
Temperature Upper: 20.01 °C
Results Upper: 0.09046 W/mK
Temperature Lower: 45.03 °C
Results Lower: 0.09123 W/mK
Percent Difference: 0.85%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 6 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-pe-	30.01	55.01	-3833	4004	0.09283
-pe-	30.01	55.01	-3836	4004	0.09286
-pe-	30.01	55.01	-3838	4004	0.09289
-pe-	30.00	55.01	-3839	4006	0.09292
-pe-	30.00	55.01	-3841	4002	0.09290
-pe-	30.01	55.01	-3843	4004	0.09295
-pe-	30.00	55.00	-3844	4001	0.09294
-pe-	30.00	55.01	-3845	4005	0.09299
-pe-	30.00	55.01	-3847	4004	0.09301

-pe-	30.00	55.01	-3847	4009	0.09305

Friday, August 24, 2012, Time 01:10

Setpoint No. 6
Setpoint Upper: 29.99 °C
Setpoint Lower: 55.00 °C
Temperature Upper: 30.00 °C
Results Upper: 0.09206 W/mK
Temperature Lower: 55.01 °C
Results Lower: 0.09397 W/mK
Percent Difference: 2.05%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 7 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	40.04	65.05	-3925	4243	0.09563
-pe-	40.05	65.06	-3948	4218	0.09556
-pe-	40.04	65.06	-3965	4196	0.09549
-pe-	40.03	65.05	-3977	4176	0.09541
-pe-	40.02	65.03	-3985	4164	0.09539
-pe-	40.02	65.02	-3991	4155	0.09536
-pe-	40.01	65.01	-3993	4151	0.09537
-pe-	40.01	65.01	-3994	4156	0.09542
-pe-	40.01	65.01	-3994	4153	0.09540
-pe-	40.00	65.01	-3994	4151	0.09537

Friday, August 24, 2012, Time 02:49

Setpoint No. 7
Setpoint Upper: 40.00 °C
Setpoint Lower: 65.00 °C
Temperature Upper: 40.01 °C
Results Upper: 0.09405 W/mK
Temperature Lower: 65.01 °C
Results Lower: 0.09675 W/mK
Percent Difference: 2.83%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00

Min Number of Blocks: 4
Calculation Blocks: 3

Block Averages for setpoint 8 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	50.05	75.04	-4059	4401	0.09798
-pe-	50.05	75.05	-4078	4382	0.09796
-pe-	50.04	75.04	-4096	4358	0.09788
-pe-	50.04	75.03	-4110	4337	0.09780
-pe-	50.03	75.02	-4118	4328	0.09782
-pe-	50.02	75.02	-4123	4324	0.09782
-pe-	50.02	75.01	-4125	4321	0.09782
-pe-	50.01	75.01	-4127	4316	0.09777
-pe-	50.02	75.02	-4129	4322	0.09784
-pe-	50.01	75.01	-4129	4314	0.09775

Friday, August 24, 2012, Time 04:27

Setpoint No. 8
Setpoint Upper: 50.00 °C
Setpoint Lower: 75.00 °C
Temperature Upper: 50.01 °C
Results Upper: 0.09570 W/mK
Temperature Lower: 75.01 °C
Results Lower: 0.09987 W/mK
Percent Difference: 4.26%

Experiment's Criteria:
Temperature Equilibrium: 0.20
Between Block HFM Equil.: 49
HFM Percent Change:2.00
Min Number of Blocks: 4
Calculation Blocks: 3

Results Table -- SI Units

Mean Temp	Upper Cond	Lower Cond	Average Cond
-7.51	0.08398	0.08121	0.08259
2.50	0.08500	0.08406	0.08453
12.50	0.08651	0.08660	0.08655
22.51	0.08838	0.08894	0.08866
32.52	0.09046	0.09123	0.09084
42.51	0.09206	0.09397	0.09302
52.51	0.09405	0.09675	0.09540
62.51	0.09570	0.09987	0.09778

Polymer Bock B001											
			Test 1 (31)		Test 2 (32)		Test 3 (33)		Test 4 (40)		Average Lambda (W/mK)
Set point	**Temp Upper (℃)**	**Temp Lower (℃)**	**Mean Temp (℃)**	**Lambda (W/mK)**	**Mean Temp (℃)**	**Lambda (W/mK)**	**Mean Temp (℃)**	**Lambda (W/mK)**	**Mean Temp (℃)**	**Lambda (W/mK)**	
1	-20	5	-7.5	0.112	-7.5	0.109	-7.5	0.110	-7.5	0.109	0.109
2	-10	15	2.5	0.114	2.5	0.111	2.5	0.112	2.5	0.111	0.111
3	0	25	12.5	0.117	12.5	0.114	12.5	0.114	12.5	0.113	0.113
4	10	35	22.51	0.119	22.51	0.116	22.5	0.116	22.5	0.115	0.116
5	20	45	32.51	0.121	32.51	0.118	32.5	0.118	32.5	0.117	0.118
6	30	55	42.51	0.123	42.51	0.120	42.5	0.120	42.5	0.119	0.120
7	40	65	52.5	0.127	52.51	0.122	52.5	0.122	52.5	0.122	0.122
8	50	75	62.52	0.130	62.51	0.125	62.5	0.124	62.5	0.124	0.124

Polymer Bock B002											
			Test 1 (34)		Test 2 (35)		Test 3 (36)		Test 4 (41)		Average Lambda (W/mK)
Set point	**Temp Upper (℃)**	**Temp Lower (℃)**	**Mean Temp (℃)**	**Lambda (W/mK)**	**Mean Temp (℃)**	**Lambda (W/mK)**	**Mean Temp (℃)**	**Lambda (W/mK)**	**Mean Temp (℃)**	**Lambda (W/mK)**	
1	-20	5	-7.5	0.081	-7.5	0.078	-7.5	0.081	-7.5	0.078	0.079
2	-10	15	2.5	0.083	2.5	0.079	2.5	0.082	2.5	0.080	0.081
3	0	25	12.5	0.085	12.5	0.082	12.5	0.085	12.5	0.082	0.083
4	10	35	22.5	0.087	22.5	0.084	22.5	0.087	22.5	0.084	0.085
5	20	45	32.5	0.089	32.5	0.086	32.5	0.089	32.5	0.086	0.088
6	30	55	42.5	0.092	42.5	0.088	42.5	0.091	42.5	0.088	0.090
7	40	65	52.5	0.094	52.5	0.090	52.5	0.093	52.5	0.091	0.092
8	50	75	62.5	0.097	62.5	0.092	62.5	0.095	62.5	0.092	0.094

Polymer Bock B003			**Test 1 (37)**	
Set point	Temp Upper (℃)	Temp Lower (℃)	Mean Temp (℃)	Lambda (W/mK)
1	-20	5	-7.5	0.083
2	-10	15	2.5	0.085
3	0	25	12.5	0.087
4	10	35	22.5	0.089
5	20	45	32.5	0.091
6	30	55	42.5	0.093
7	40	65	52.5	0.095
8	50	75	62.5	0.098

LASERCOMP FOX50

Monday, November 12, 2012, Time 18:27

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb31
Thickness: 25.15mm
Contact Resistance: 0.00000
[B001 31 49.1g 22C 58%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.02	10.01	522	-595	0.1049
-pe-	30.02	10.02	521	-596	0.1050
-pe-	30.02	10.01	522	-595	0.1049
-pe-	30.02	10.01	521	-596	0.1050
-pe-	30.02	10.01	522	-596	0.1050
-pe-	30.02	10.01	522	-595	0.1049
-pe-	30.02	10.01	521	-596	0.1049
-pe-	30.02	10.01	522	-596	0.1050
-pe-	30.02	10.01	521	-597	0.1049
-pe-	30.02	10.01	521	-597	0.1050

Monday, November 12, 2012, Time 21:23

Setpoint No.	1	
Thickness: 25.15	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	479	µV
ZeroCal Offset Upper:	42	
CalibFactor Upper:	0.164522	
Results Upper:	0.09905	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-531	µV
ZeroCal Offset Lower:	-65	
CalibFactor Lower:	0.166015	
Results Lower:	0.1109	W/mK
Temperature Average:	20.0	°C
Results Average:	0.105	W/mK
Resistance Avg :	0.240	m²K/W
R/unit Avg :	9.53	mK/W
Total Thermal Resistance:	0.240	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Sunday, November 11, 2012, Time 18:00

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb1
Thickness: 24.80mm
Contact Resistance: 0.00000
[B001 32 43.7gms - 18C 60%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.02	10.01	608	-583	0.1112
-pe-	30.02	10.02	608	-583	0.1112
-pe-	30.02	10.01	608	-584	0.1112
-pe-	30.02	10.01	608	-583	0.1112
-pe-	30.02	10.01	607	-584	0.1111
-pe-	30.02	10.01	607	-584	0.1112
-pe-	30.02	10.01	607	-584	0.1111
-pe-	30.02	10.01	607	-584	0.1112
-pe-	30.02	10.01	607	-584	0.1111
-pe-	30.02	10.02	606	-585	0.1111

✓

Sunday, November 11, 2012, Time 19:37

Setpoint No.	1	
Thickness: 24.80	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	565	µV
ZeroCal Offset Upper:	41	
CalibFactor Upper:	0.164522	
Results Upper:	0.1153	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-520	µV
ZeroCal Offset Lower:	-64	
CalibFactor Lower:	0.166015	
Results Lower:	0.1070	W/mK
Temperature Average:	20.0	°C
Results Average:	0.111	W/mK
Resistance Avg :	0.223	m²K/W
R/unit Avg :	9.00	mK/W
Total Thermal Resistance:	0.223	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Monday, November 12, 2012, Time 15:48

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb33
Thickness: 24.05mm
Contact Resistance: 0.00000
[B001 33 53.6g 20C 58%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.02	10.01	532	-601	0.1026
-pe-	30.02	10.01	532	-601	0.1025
-pe-	30.02	10.01	532	-602	0.1025
-pe-	30.02	10.01	532	-602	0.1025
-pe-	30.02	10.01	532	-602	0.1025
-pe-	30.02	10.01	532	-602	0.1026
-pe-	30.02	10.01	532	-602	0.1025
-pe-	30.02	10.01	531	-602	0.1026
-pe-	30.02	10.01	531	-603	0.1025
-pe-	30.02	10.01	531	-603	0.1026

Monday, November 12, 2012, Time 18:25

Setpoint No.	1		
Thickness: 24.05	mm		
Setpoint Upper:	30.0	°C	
Setpoint Lower:	10.0	°C	
Temperature Upper:		30.0	°C
Heat Flow Upper:		492	µV
ZeroCal Offset Upper:		40	
CalibFactor Upper:		0.164521	
Results Upper:		0.09724	W/mK
Temperature Lower:		10.0	°C
Heat Flow Lower:		-540	µV
ZeroCal Offset Lower:		-62	
CalibFactor Lower:		0.166015	
Results Lower:		0.1079	W/mK
Temperature Average:		20.0	°C
Results Average:		0.103	W/mK
Resistance Avg :		0.235	m^2K/W
R/unit Avg :		9.75	mK/W
Total Thermal Resistance:		0.235	m^2K/W

Contact Resistance used(x2): 0.0000000 m^2K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Monday, November 12, 2012, Time 11:17

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb34
Thickness: 23.19mm
Contact Resistance: 0.00000
[B002 34 35.3g 18C 58%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [μV]	Qlower [μV]	Lambda [W/mK]
-pe-	30.02	10.01	447	-471	0.07861
-pe-	30.02	10.01	446	-472	0.07857
-pe-	30.02	10.01	446	-472	0.07862
-pe-	30.02	10.01	446	-472	0.07857
-pe-	30.02	10.01	446	-472	0.07863
-pe-	30.02	10.01	445	-472	0.07856
-pe-	30.02	10.01	445	-473	0.07862
-pe-	30.02	10.01	445	-473	0.07860
-pe-	30.02	10.01	445	-473	0.07859
-pe-	30.02	10.01	445	-473	0.07861

Monday, November 12, 2012, Time 12:51

Setpoint No.	1	
Thickness: 23.19	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	408	μV
ZeroCal Offset Upper:	38	
CalibFactor Upper:	0.164522	
Results Upper:	0.07771	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-413	μV
ZeroCal Offset Lower:	-60	
CalibFactor Lower:	0.166015	
Results Lower:	0.07950	W/mK
Temperature Average:	20.0	°C
Results Average:	0.0786	W/mK
Resistance Avg :	0.295	m²K/W
R/unit Avg :	12.7	mK/W
Total Thermal Resistance:	0.295	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200μV

Monday, November 12, 2012, Time 08:25

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb2
Thickness: 23.27mm
Contact Resistance: 0.00000
[B002 35 36.5g 18C 54%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper	Tlower	Qupper	Qlower	Lambda
	[°C]	[°C]	[µV]	[µV]	[W/mK]
-pe-	30.02	10.02	447	-471	0.07884
-pe-	30.02	10.01	446	-472	0.07885
-pe-	30.02	10.01	446	-472	0.07880
-pe-	30.02	10.01	445	-473	0.07881
-pe-	30.02	10.01	446	-472	0.07881
-pe-	30.02	10.01	446	-471	0.07877
-pe-	30.02	10.02	445	-472	0.07879
-pe-	30.02	10.01	445	-473	0.07884
-pe-	30.02	10.01	446	-472	0.07880
-pe-	30.02	10.01	444	-473	0.07876

Monday, November 12, 2012, Time 10:06

Setpoint No.	1		
Thickness: 23.27	mm		
Setpoint Upper:	30.0	°C	
Setpoint Lower:	10.0	°C	
Temperature Upper:		30.0	°C
Heat Flow Upper:		407	µV
ZeroCal Offset Upper:		38	
CalibFactor Upper:		0.164521	
Results Upper:		0.07789	W/mK
Temperature Lower:		10.0	°C
Heat Flow Lower:		-413	µV
ZeroCal Offset Lower:		-60	
CalibFactor Lower:		0.166016	
Results Lower:		0.07970	W/mK
Temperature Average:		20.0	°C
Results Average:		0.0788	W/mK
Resistance Avg :		0.295	m²K/W
R/unit Avg :		12.7	mK/W
Total Thermal Resistance:		0.295	m²K/W
Contact Resistance used(x2):		0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Monday, November 12, 2012, Time 14:52

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb36
Thickness: 23.45mm
Contact Resistance: 0.00000
[B002 36 35.8g 20C 58%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
se-	30.02	10.01	420	-461	0.07585
se-	30.02	10.01	424	-456	0.07563
pe-	30.02	10.01	426	-453	0.07559
pe-	30.02	10.01	426	-452	0.07552
pe-	30.02	10.01	426	-452	0.07548
pe-	30.02	10.01	427	-451	0.07551
pe-	30.02	10.02	426	-452	0.07552
pe-	30.02	10.01	426	-452	0.07549
pe-	30.02	10.01	426	-452	0.07549
pe-	30.02	10.01	425	-452	0.07541

Monday, November 12, 2012, Time 15:46

Setpoint No.	1	
Thickness: 23.45	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	387	µV
ZeroCal Offset Upper:	38	
CalibFactor Upper:	0.164522	
Results Upper:	0.07468	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-392	µV
ZeroCal Offset Lower:	-60	
CalibFactor Lower:	0.166015	
Results Lower:	0.07625	W/mK
Temperature Average:	20.0	°C
Results Average:	0.0755	W/mK
Resistance Avg :	0.311	m²K/W
R/unit Avg :	13.3	mK/W
Total Thermal Resistance:	0.311	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Monday, November 12, 2012, Time 10:11

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb3
Thickness: 22.70mm
Contact Resistance: 0.00000
[B003 37 36.2g 19C 54%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [μV]	Qlower [μV]	Lambda [W/mK]
-pe-	30.02	10.01	492	-524	0.08638
-pe-	30.02	10.01	493	-523	0.08634
-pe-	30.02	10.01	493	-523	0.08632
-pe-	30.02	10.01	494	-522	0.08638
-pe-	30.02	10.01	495	-521	0.08638
-pe-	30.02	10.01	495	-521	0.08636
-pe-	30.02	10.01	496	-520	0.08636
-pe-	30.02	10.01	496	-520	0.08636
-pe-	30.02	10.01	496	-520	0.08637
-pe-	30.02	10.01	496	-520	0.08636

Monday, November 12, 2012, Time 11:14

Setpoint No.	1	
Thickness: 22.70	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	460	μV
ZeroCal Offset Upper:	36	
CalibFactor Upper:	0.164522	
Results Upper:	0.08584	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-461	μV
ZeroCal Offset Lower:	-58	
CalibFactor Lower:	0.166015	
Results Lower:	0.08689	W/mK
Temperature Average:	20.0	°C
Results Average:	0.0864	W/mK
Resistance Avg :	0.263	m^2K/W
R/unit Avg :	11.6	mK/W
Total Thermal Resistance:	0.263	m^2K/W
Contact Resistance used(x2):	0.0000000	m^2K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200μV

Tuesday, November 13, 2012, Time 07:29

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb38
Thickness: 22.93mm
Contact Resistance: 0.00000
[B003 38 42.9g 24C 54%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
se-	30.02	10.01	461	-564	0.08806
se-	30.02	10.01	470	-555	0.08796
pe-	30.02	10.01	474	-548	0.08773
pe-	30.02	10.01	478	-543	0.08763
pe-	30.02	10.01	479	-542	0.08762
pe-	30.02	10.01	480	-540	0.08756
pe-	30.02	10.01	480	-540	0.08755
pe-	30.02	10.01	481	-539	0.08753
pe-	30.02	10.01	481	-540	0.08761
pe-	30.02	10.01	480	-541	0.08760

Tuesday, November 13, 2012, Time 08:27

Setpoint No.	1	
Thickness: 22.93	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	444	µV
ZeroCal Offset Upper:	37	
CalibFactor Upper:	0.164522	
Results Upper:	0.08365	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-481	µV
ZeroCal Offset Lower:	-59	
CalibFactor Lower:	0.166015	
Results Lower:	0.09149	W/mK
Temperature Average:	20.0	°C
Results Average:	0.0876	W/mK
Resistance Avg :	0.262	m²K/W
R/unit Avg :	11.4	mK/W
Total Thermal Resistance:	0.262	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Tuesday, November 13, 2012, Time 00:01

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodb39
Thickness: 22.85mm
Contact Resistance: 0.00000
[B003 39 45.8g 23C 56%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox505

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.02	10.02	472	-522	0.08483
-pe-	30.02	10.01	473	-522	0.08487
-pe-	30.02	10.01	472	-522	0.08485
-pe-	30.02	10.01	472	-522	0.08486
-pe-	30.02	10.01	472	-522	0.08483
-pe-	30.02	10.01	473	-522	0.08484
-pe-	30.02	10.01	472	-522	0.08483
-pe-	30.02	10.02	472	-522	0.08481
-pe-	30.02	10.01	472	-522	0.08487
-pe-	30.02	10.01	472	-523	0.08487

Tuesday, November 13, 2012, Time 03:01

Setpoint No.	1	
Thickness: 22.85	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	435	µV
ZeroCal Offset Upper:	37	
CalibFactor Upper:	0.164522	
Results Upper:	0.08183	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-463	µV
ZeroCal Offset Lower:	-59	
CalibFactor Lower:	0.166015	
Results Lower:	0.08786	W/mK
Temperature Average:	20.0	°C
Results Average:	0.0848	W/mK
Resistance Avg :	0.269	m²K/W
R/unit Avg :	11.8	mK/W
Total Thermal Resistance:	0.270	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Tuesday, November 13, 2012, Time 12:42

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodhw5
Thickness: 21.20mm
Contact Resistance: 0.00000
[hardwood 5 21.3g 20C 58%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.02	10.01	516	-508	0.08199
-pe-	30.02	10.01	516	-508	0.08197
-pe-	30.02	10.01	515	-508	0.08193
-pe-	30.02	10.01	516	-508	0.08196
-pe-	30.02	10.01	515	-508	0.08192
-pe-	30.02	10.01	516	-507	0.08198
-pe-	30.02	10.01	516	-507	0.08195
-pe-	30.02	10.01	517	-507	0.08195
-pe-	30.02	10.01	518	-506	0.08198
-pe-	30.02	10.01	518	-506	0.08196

0·082

Tuesday, November 13, 2012, Time 13:56

Setpoint No.	1	
Thickness: 21.20	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	484	µV
ZeroCal Offset Upper:	33	
CalibFactor Upper:	0.164522	
Results Upper:	0.08439	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-452	µV
ZeroCal Offset Lower:	-54	
CalibFactor Lower:	0.166015	
Results Lower:	0.07954	W/mK
Temperature Average:	20.0	°C
Results Average:	0.0820	W/mK
Resistance Avg :	0.259	m²K/W
R/unit Avg :	12.2	mK/W
Total Thermal Resistance:	0.259	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Sunday, November 11, 2012, Time 15:26

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodh6
Thickness: 25.50mm
Contact Resistance: 0.00000
[hardwood 6 23.2gms - actual 26.4thick 15C 64%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.02	10.01	604	-582	0.1134
-pe-	30.02	10.01	604	-583	0.1135
-pe-	30.02	10.01	604	-583	0.1135
-pe-	30.02	10.01	603	-583	0.1134
-pe-	30.02	10.01	603	-583	0.1134
-pe-	30.02	10.01	603	-583	0.1134
-pe-	30.02	10.01	603	-584	0.1135
-pe-	30.02	10.01	602	-584	0.1134
-pe-	30.02	10.01	602	-584	0.1134
-pe-	30.02	10.01	603	-584	0.1135

× $26.4/25.5$ = 0.117 W/mK

Sunday, November 11, 2012, Time 17:03

Setpoint No. 1
Thickness: 25.50 mm
Setpoint Upper: 30.0 °C
Setpoint Lower: 10.0 °C
Temperature Upper: 30.0 °C
Heat Flow Upper: 559 µV
ZeroCal Offset Upper: 43
CalibFactor Upper: 0.164522
Results Upper: 0.1173 W/mK
Temperature Lower: 10.0 °C
Heat Flow Lower: -518 µV
ZeroCal Offset Lower: -66
CalibFactor Lower: 0.166015
Results Lower: 0.1096 W/mK
Temperature Average: 20.0 °C
Results Average: 0.113 W/mK
Resistance Avg : 0.225 m²K/W
R/unit Avg : 8.82 mK/W
Total Thermal Resistance: 0.225 m²K/W
Contact Resistance used(x2): 0.0000000 m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Tuesday, November 13, 2012, Time 13:58

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodhw7
Thickness: 21.40mm
Contact Resistance: 0.00000
[hardwood 7 25.0g 20C 60%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-pe-	30.03	10.02	579	-564	0.09318
-pe-	30.02	10.02	579	-564	0.09327
-pe-	30.02	10.01	580	-564	0.09327
-pe-	30.02	10.01	579	-564	0.09326
-pe-	30.02	10.01	578	-565	0.09322
-pe-	30.02	10.02	577	-565	0.09319
-pe-	30.02	10.02	577	-566	0.09320
-pe-	30.02	10.02	575	-568	0.09320
-pe-	30.02	10.02	574	-568	0.09316
-pe-	30.02	10.02	573	-569	0.09313

Tuesday, November 13, 2012, Time 15:10

Setpoint No.	1		
Thickness: 21.40	mm		
Setpoint Upper:	30.0	°C	
Setpoint Lower:	10.0	°C	
Temperature Upper:		30.0	°C
Heat Flow Upper:		542	µV
ZeroCal Offset Upper:		33	
CalibFactor Upper:		0.164522	
Results Upper:		0.09535	W/mK
Temperature Lower:		10.0	°C
Heat Flow Lower:		-512	µV
ZeroCal Offset Lower:		-55	
CalibFactor Lower:		0.166015	
Results Lower:		0.09101	W/mK
Temperature Average:		20.0	°C
Results Average:		0.0932	W/mK
Resistance Avg :		0.230	m²K/W
R/unit Avg :		10.7	mK/W
Total Thermal Resistance:		0.230	m²K/W
Contact Resistance used(x2):		0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Tuesday, November 13, 2012, Time 08:29

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodsw5
Thickness: 23.30mm
Contact Resistance: 0.00000
[softwood 5 20.1g 23C 54%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
pe-	30.02	10.01	515	-521	0.09026
pe-	30.02	10.02	514	-521	0.09020
pe-	30.02	10.01	514	-522	0.09023
pe-	30.02	10.01	514	-522	0.09025
pe-	30.02	10.01	513	-522	0.09017
pe-	30.02	10.02	512	-522	0.09015
pe-	30.02	10.02	511	-523	0.09017
pe-	30.02	10.01	511	-523	0.09014
pe-	30.02	10.01	510	-524	0.09007
pe-	30.02	10.01	510	-524	0.09009

Tuesday, November 13, 2012, Time 09:49

Setpoint No. 1
Thickness: 23.30 mm
Setpoint Upper: 30.0 °C
Setpoint Lower: 10.0 °C
Temperature Upper: 30.0 °C
Heat Flow Upper: 473 µV
ZeroCal Offset Upper: 38
CalibFactor Upper: 0.164522
Results Upper: 0.09070 W/mK
Temperature Lower: 10.0 °C
Heat Flow Lower: -463 µV
ZeroCal Offset Lower: -60
CalibFactor Lower: 0.166015
Results Lower: 0.08955 W/mK
Temperature Average: 20.0 °C
Results Average: 0.0901 W/mK
Resistance Avg : 0.259 m²K/W
R/unit Avg : 11.1 mK/W
Total Thermal Resistance: 0.259 m²K/W
Contact Resistance used(x2): 0.0000000 m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Sunday, November 11, 2012, Time 14:34

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woods6
Thickness: 25.50mm
Contact Resistance: 0.00000
[softwood 6 22.2gms - actual 28.03thick 14C 65%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

Corrected for actual t 28.03 mm / 25.5 m

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
-se-	30.03	10.02	608	-474	0.1025
-se-	30.03	10.02	589	-493	0.1024
-se-	30.03	10.02	578	-505	0.1026
-se-	30.03	10.02	570	-512	0.1025
-pe-	30.02	10.02	566	-516	0.1025
-pe-	30.02	10.02	563	-519	0.1024
-pe-	30.02	10.02	562	-520	0.1025
-pe-	30.02	10.02	560	-522	0.1024
-pe-	30.02	10.01	559	-523	0.1024
-pe-	30.02	10.01	558	-523	0.1024

× 28.0/25.5 = 0.112 W/m·K.

Sunday, November 11, 2012, Time 15:24

Setpoint No.	1	
Thickness: 25.50	mm	
Setpoint Upper:	30.0	°C
Setpoint Lower:	10.0	°C
Temperature Upper:	30.0	°C
Heat Flow Upper:	517	µV
ZeroCal Offset Upper:	43	
CalibFactor Upper:	0.164522	
Results Upper:	0.1084	W/mK
Temperature Lower:	10.0	°C
Heat Flow Lower:	-456	µV
ZeroCal Offset Lower:	-66	
CalibFactor Lower:	0.166015	
Results Lower:	0.09639	W/mK
Temperature Average:	20.0	°C
Results Average:	0.102	W/mK
Resistance Avg :	0.249	m²K/W
R/unit Avg :	9.76	mK/W
Total Thermal Resistance:	0.250	m²K/W
Contact Resistance used(x2):	0.0000000	m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Tuesday, November 13, 2012, Time 09:51

WinTherm50 Version 2.31.08
Instrument Program Version 150

File Name: woodsw7
Thickness: 23.25mm
Contact Resistance: 0.00000
[softwood 7 22.8g 23C 54%]
Thickness obtained : user entered

TEST RUN

Calibration used : Two Thickness
Calibration File Id: PERSPEX

Number of Setpoints: 1

ZeroCal File Name: C:\Documents and Settings\John\My Documents\LaserComp\WinTherm50v2\zero(fox5052

Gain Level: 7

Block Averages for setpoint 1 in SI units

	Tupper [°C]	Tlower [°C]	Qupper [µV]	Qlower [µV]	Lambda [W/mK]
pe-	30.02	10.01	561	-551	0.09743
pe-	30.02	10.01	562	-550	0.09746
pe-	30.02	10.01	562	-550	0.09744
pe-	30.02	10.01	562	-550	0.09742
pe-	30.02	10.02	562	-550	0.09742
pe-	30.02	10.01	562	-550	0.09743
pe-	30.02	10.02	562	-550	0.09744
pe-	30.02	10.02	562	-551	0.09743
pe-	30.02	10.01	563	-550	0.09743
pe-	30.02	10.02	561	-550	0.09739

Tuesday, November 13, 2012, Time 12:40

Setpoint No. 1
Thickness: 23.25 mm
Setpoint Upper: 30.0 °C
Setpoint Lower: 10.0 °C
Temperature Upper: 30.0 °C
Heat Flow Upper: 524 µV
ZeroCal Offset Upper: 38
CalibFactor Upper: 0.164522
Results Upper: 0.1003 W/mK
Temperature Lower: 10.0 °C
Heat Flow Lower: -490 µV
ZeroCal Offset Lower: -60
CalibFactor Lower: 0.166015
Results Lower: 0.09458 W/mK
Temperature Average: 20.0 °C
Results Average: 0.0974 W/mK
Resistance Avg : 0.239 m²K/W
R/unit Avg : 10.3 mK/W
Total Thermal Resistance: 0.239 m²K/W
Contact Resistance used(x2): 0.0000000 m²K/W

Thermal Equilibrium Criteria:
Temperature Equilibrium: 1.00°C
Between Block HFM Equil.: 200µV

Appendix G – Dimensional Stability Analysis

		1	2	3	4	5	6	7	8	9
B001	Number	Before Oven					After Oven			
		Dry Weight (g)	Wet Weight (g)	Height (mm)	Width (mm)	Length (mm)	Weight (g)	Height (mm)	Width (mm)	Length (mm)
70˚C	1	373.45	377.97	24.68	123.87	150.01	373.91	24.68	123.88	149.90
	2	374.41	378.11	24.74	123.80	149.84	374.86	24.84	123.77	149.90
100˚C	9	371.63	376.83	24.75	123.96	149.91	371.39	28.23	130.57	141.13
	23	386.11	390.01	24.75	123.74	149.57	385.85	28.62	131.72	140.34

B002	Number	Before Oven					After Oven			
		Dry Weight (g)	Wet Weight (g)	Height	Width	Length	Weight (g)	Height (mm)	Width (mm)	Length (mm)
70˚C	26	287.47	290.78	24.75	123.87	149.82	283.47	24.47	123.95	149.75
	27	287.73	290.72	24.75	123.80	149.05	287.81	24.35	123.29	149.19
100˚C	13	286.20	290.37	24.77	123.90	149.55	286.06	27.86	130.35	130.26
	15	297.20	300.81	24.78	123.90	146.67	297.05	28.16	130.39	132.23

B003	Number	Before Oven					After Oven			
		Dry Weight (g)	Wet Weight (g)	Height	Width	Length	Weight (g)	Height (mm)	Width (mm)	Length (mm)
70˚C	29	318.92	322.46	24.71	123.79	149.91	319.02	24.37	123.94	149.70
	30	318.98	322.84	24.66	123.76	149.87	319.10	24.76	123.97	149.57
100˚C	17	318.10	322.91	24.34	123.79	149.58	317.75	25.34	124.86	142.99

	18	327.29	331.98	24.44	123.86	149.72	326.93	25.64	125.61	143.09

TSW	Number	Before Oven					After Oven			
		Dry Weight (g)	Wet Weight (g)	Height	Width	Length	Weight (g)	Height (mm)	Width (mm)	Length (mm)
70˚C	7	244.64	505.61	41.73	92.42	149.94	266.70	42.34	92.49	149.98
	8	246.35	507.34	41.65	92.11	149.94	267.87	41.93	92.01	149.93
100˚C	2	278.36	617.93	47.88	99.90	150.37	264.51	47.08	99.92	150.02
	3	284.22	625.95	48.16	99.92	150.26	267.11	47.97	99.85	150.33

SWD	Number	Before Oven					After Oven			
		Dry Weight (g)	Wet Weight (g)	Height	Width	Length	Weight (g)	Height (mm)	Width (mm)	Length (mm)
70˚C	2	239.58	456.78	26.90	141.01	149.58	216.90	26.65	140.22	149.68
100˚C	1	247.90	467.29	26.95	140.78	149.46	222.36	26.98	139.19	149.79

HWD	Number	Before Oven					After Oven			
		Dry Weight (g)	Wet Weight (g)	Height	Width	Length	Weight (g)	Height (mm)	Width (mm)	Length (mm)
70˚C	3	213.77	387.18	21.78	145.44	149.57	196.15	21.76	145.20	149.67
100˚C	2	207.57	382.86	21.58	145.40	149.31	188.00	21.64	145.38	149.74

moisture content (ω)	70˚C	100˚C
B001	0.976	1.271
B002	1.795	1.386
B003	1.125	1.584
TSW	89.489	133.977
SWD	110.595	110.150
HWD	97.390	103.649

Shrinkage Limit (SL)	High @ 70˚C	Width @ 70˚C	Length @ 70˚C	High @ 100˚C	Width @ 100˚C	Length @ 100˚C
B001	-0.20	0.01	0.05	-14.85	-5.89	6.01
B002	1.37	0.17	0.04	-13.06	-5.22	11.37
B003	0.49	-0.15	0.17	-4.51	-1.14	4.42
TSW	-1.07	0.02	-0.03	1.03	0.03	-0.04
SWD	0.93	0.56	-0.07	-0.11	1.13	-0.22
HWD	-0.09	0.17	-0.07	-0.28	0.01	-0.29

Coefficient of Thermal Expansion (α)	70˚C	100˚C
B001	9.5E-06	0.000752
B002	8.7E-06	0.001421
B003	3.4E-05	0.000552
TSW	-6E-06	-5E-06
SWD	-1.3E-05	-2.8E-05
HWD	-1.3E-05	-3.6E-05

Coefficient of Linear Expansion	70˚C	100˚C
B001	0.000475	0.060139
B002	0.000435	0.11372
B003	0.001701	0.04417
TSW	-0.0003	-0.0004
SWD	-0.00067	-0.00221
HWD	-0.00067	-0.00288